Chapter 4: SOURCE-BY-SOURCE ANALYSIS OF THE EFFECTIVENESS AND COSTS OF A TAX ON SULFUR EMISSIONS

4.1 Introduction

This chapter provides an analysis of the projected effectiveness and costs of a tax on sulfur emissions for each of the major sources examined in this study--steam-electric utilities, area sources, petroleum refineries, sulfuric acid plants, and primary nonferrous smelters. A discussion of the indirect impact of the tax on fuel demand and prices is also included.

Many of the control techniques for reducing sulfur emissions from the sources being examined in this study result in the recovery of sulfur or sulfuric acid.* If the market for sulfur or sulfuric acid proves to be sufficiently large to absorb the quantities recovered, revenues from such sales would lower control costs. The lower costs should encourage greater levels of control for a given tax rate. However, there are several cogent reasons for concluding that future prices for recovered sulfur and sulfuric acid will go below their currently depressed levels.† With only limited prospects of future markets for sulfur, some firms may actually face a dispoal problem (i.e., a negative price) with respect to their recovered sulfur. Therefore, for the industrial process sources (petroleum refineries; sulfuric acid producers; copper, lead, and zinc smelters), the sensitivity of the projected effectiveness and costs of the tax to changes in values of recovered sulfur and sulfuric acid is also provided.

Finally, because of the difficulty in accounting for all of the process and operating configurations that influence control costs, the sensitivity of the projected effectiveness and costs of the tax to alternative control cost estimates is also analyzed.

4.2 Steam-Electric Power Plants

Projections of the response of the nation's steam-electric power plants to a tax on sulfur emissions have been made on a utility-by-utility basis using the emissions and control data and the fuels availability data and price information shown in appendix A. The projected responses of all

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*Sulfuric acid is about 33 percent elemental sulfur, by weight.

†See appendix E for further discussion on this topic.

the nation's utilities have been summed to obtain industry totals. The resulting projections, however, are approximations that do not reflect all of the control alternatives nor fuel availabilities and transportation strategy costs among utilities. The omitted hardware strategies were generally those that are currently considered highly experimental and that are not currently expected to be available by 1978.

4.2.1 Background

In 1968, combustion of fossil fuels by steam-electric utilities accounted for an estimated 50.6 percent of the estimated nationwide sulfur emissions from all sources.*

In 1970, installed steam-electric generating capacity of the 953 plants was 260,272.1 thousand kilowatts; actual generation was 1,220.1 billion kilowatthours.† An additional 269 billion kilowatthours were produced by hydroelectric nuclear generating stations. Utilities are either investor owned, publicly owned (non-Federal), federally owned, or owned by cooperatives. This industry is subject to comprehensive rate and service regulation on the part of governmental commissions at several levels of government.

4.2.2 Industry Growth

From 1957 through 1970, steam-electric-generated electricity increased an average of 7.4 percent annually. However, as shown in figure 10, growth has varied throughout the period.

Generation of electricity by steam-electric power plants is projected to increase about 3.6 percent annually between 1970 and 1978.‡ Actual generation is therefore projected to be about 1,631.0 billion kilowatthours.

4.2.3 Effectiveness

The response of the nation's steam-electric utilities to a tax on their emissions of sulfur has been projected for selected tax rates.

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*National Air Pollution Control Administration. Nationwide Inventory of Air Pollutant Emissions,--1968, Raleigh, N. C., August 1970.

†National Coal Association, Division of Economics and Statistics, Steam-Electric Plant Factors--1969, Washington, D. C., 1969, p. 118.

‡National Economic Research Associates, Inc., Fuels for the Electric Utility Industry, 1971-1985, Prepared for the Edison Electric Institute, New York, N. Y., August 1972.

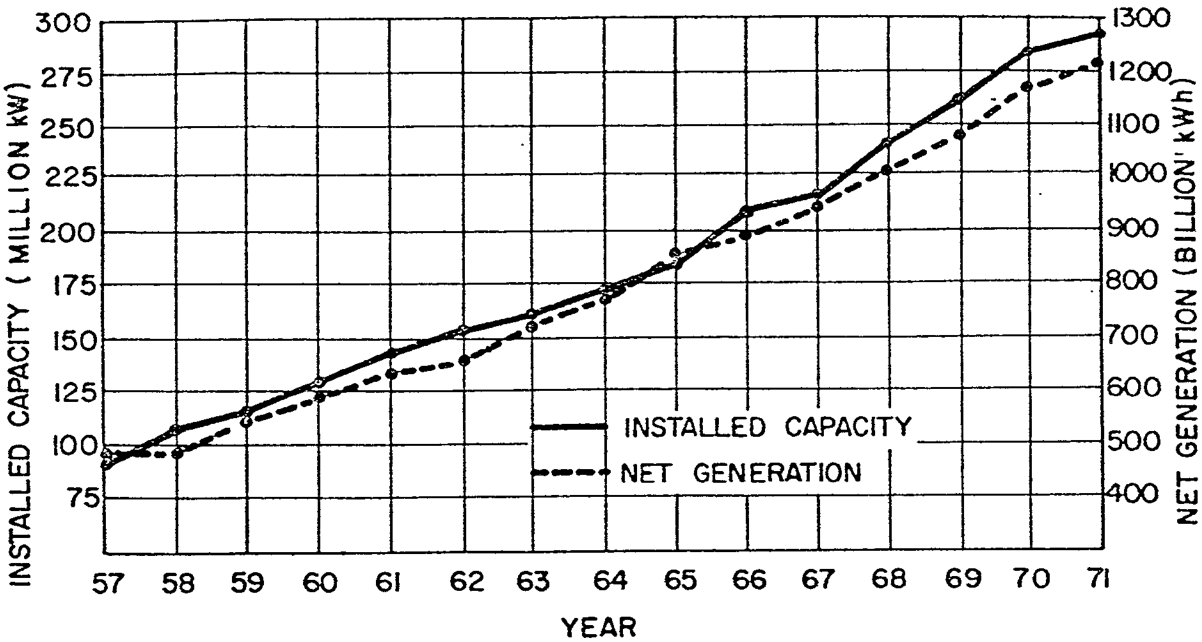

Figure 10. Steam-electric power plant trends (Source: National Coal Association).

One considered control alternative used, magnesia base scrubbing, produces sulfur which can be sold to offset some control costs. It has been assumed that the recovered sulfur can be sold at $10 per ton, although, as discussed in appendix E, there is considerable uncertainty regarding the 1978 market value of sulfur. However, a brief analysis has confirmed that this value does not significantly alter the projected effectiveness and costs of a tax in the case of the steam-electric utilities.

Since, sulfur emissions from steam-electric utilities are, in the absence of flue gas desulfurization, a function of the amount and sulfur content of the fuels consumed, projections of fuel demands, supplies, and prices are needed to project fuel utilization and emissions.

As discussed in appendix A, projecting long-run fuel supplies and price requires a knowledge of many technical, economic, and even political factors. This research has provided only an initial examination of how these factors may interrelate in 1978 with projected fuel demands to determine future fuels usage and the resulting emissions. Using fuels supply data as presented in appendix A for each major supplying region and for several fuel sulfur contents, these supplies have been allocated to utilities by establishing prices consistent with projected supplies. The future supplies of coal and domestic residual oil were assumed to grow at the maximum rates hypothesized by MITRE.* The supply of imported oil was assumed to be perfectly elastic at prices given in a recent study.† Gas was assumed to be available only to current users.

Within the model employed for this study, the demand for Coal-supplied Btu's can be met by purchasing any one of 9 sulfur content coals from 19 producing regions. Residual oil demand can be met by purchasing any one of 5 sulfur contents from 12 origins, including imports. For gas demand, 1 sulfur content and 12 origins have been used. Prices at the mine or wellhead plus transportation costs equal the delivered prices at the utility. An estimate of minimum mine and wellhead prices from a previous study for EPA† provided initial selling prices for domestically produced fuels. In cases where these prices caused fuel demand to exceed supply, the prices were increased until fuel demand was less than or approximately equal to supply on a national basis. It is recognized that this procedure does not incorporate all of the sophistication desirable; yet within the more limited scope of this study, it does provide a reasonable basis for developing a structure of relative fuel prices by sulfur content and location.

Sulfur emissions from all steam-electric plants, assuming no additional controls other than those required by the New Source Performance Standards (a zero tax) are projected to be about 11 million tons in 1978 (see table 7). Coal burning accounts for 77 percent of these emissions. The remaining 23 percent is accounted for by residual oil combustion. The contribution by gas is negligible.

Utilities can control sulfur emissions by two general approaches--fuel switching‡ or installation of control equipment. As discussed in appendix A, the only fuel switching permitted is from coal to oil. Three control systems (dry limestone, wet limestone, and magnesia scrubbing) are assumed available. The utilities are assumed to minimize total costs, defined as the sum of control costs, delivered fuel premiums, and tax payments. This assumption

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*MITRE Corporation, Survey of Coal Availabilities by Sulfur Content, May 1972.

†Battelle Memorial Institute, EPA Energy Quality Model, September 1972.

‡For this study, "fuel switching" means substitution of a fuel of a different sulfur content from that projected in the absence of a tax. It may be either the same type of fuel as purchased without a tax or an alternative fuel.

Table 7. Projected sulfur emissions from steam-electric utilities--1978*

Source	Annual sulfur emissions (thousand tons of sulfur)
Coal combustion	8,781
Oil combustion	2,615
Gas combustion	0
Total	11,396

*Assuming only controls required by New Source Performance Standards.

Source: Research Triangle Institute.

follows the conclusions of a recent EPA-sponsored study which concluded that, for a number of reasons, utilities can be expected to follow cost-minimizing behavior.*

The projected response of all steam-electric utilities to the sulfur tax for selected tax rates are provided in table 8 and in figure 11. Control costs and fuel prices by sulfur content and origin as used for this analysis are presented in appendix A. The results displayed here indicate some important results. Although reductions in emissions are induced by higher tax rates throughout the range of tax rates considered, only comparatively small additional reductions are induced at rates above 15 cents per pound. This exponential relationship between emissions tax rates and emissions reductions implies, for example, that a tax of 15 cents would induce emissions reductions 46 percent greater than those at a 5-cent tax rate. Doubling the tax to 30 cents would precipitate only a 9-percent increase in reductions over those that would occur at a 15-cent tax rate.

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*Institute of Public Administration, Governmental Approaches to Air Pollution Control: A Compendium and Annotated Bibliography, Submitted to Office of Air Programs, Environmental Protection Agency, July 15, 1971 (NTIS: PB-203 111).

Table 8. Projected response of all steam-electric power plants national tax on sulfur emissions--1978 (recovered sulfur valued at $10 per ton)

Emissions source	Emissions (thousand tons)	Reductions in emissions from zero tax (thousand tons)	Total annualized cost (thousands)	Annualized control cost (thousands)	Annual tax payment (thousands)
		Tax rate: 5 cents per pound of sulfur emissions			
Coal combustion	4,731.4	5,478.7	$1,056,152	$582,990	$473,163
Oil combustion	427.4	758.3	115,635	72,891	42,744
Gas combustion	0.2	0.0	21	0	21
Total from all sources	5,159.0	6,237.0	$1,171,808	$ 655,881	$515,928
		Tax rate: 10 cents per pound of sulfur emissions			
Coal combustion	2,675.8	7,534.4	$1,595,971	$1,060,758	$535,214
Oil combustion	285.8	899.8	178,648	121,472	57,176
Gas combustion	0.2	0.0	42	1	42
Total from all sources	2,961.8	8,434.2	$1,774,661	$1,182,231	$592,432
		Tax rate: 15 cents per pound of sulfur emissions			
Coal combustion	2,055.6	8,154.6	$1,986,655	$1,369,909	$616,749
Oil combustion	221.9	963.6	228,350	161,747	66,604
Gas combustion	0.2	0.0	64	0	64
Total from all sources	2,277.7	9,118.2	$2,215,069	$1,531,656	$683,417
		Tax rate: 20 cents per pound of sulfur emissions			
Coal combustion	1,745.3	8,464.0	$2,316,748	$1,618,123	$698,625
Oil combustion	201.7	983.7	272,855	192,172	80,684
Gas combustion	0.2	0.0	85	0	85
Total from all sources	1,948.2	9,447.7	$2,589,688	$1,810,295	$779,394
		Tax rate: 25 cents per pound of sulfur emissions			
Coal combustion	1,413.1	8,797.3	$2,596,415	$1,889,803	$706,614
Oil combustion	186.2	999.2	315,361	222,245	93,116
Gas combustion	0.2	0.0	106	0	106
Total from all sources	1,599.5	9,796.5	$2,911,882	$2,112,048	$799,836
		Tax rate: 30 cents per pound of sulfur emissions			
Coal combustion	1,253.6	8,956.8	$2,830,658	$2,078,415	$752,244
Oil combustion	178.3	1,007.1	355,590	248,577	107,013
Gas combustion	0.2	0.0	127	0	127
Total from all sources	1,432.1	9,963.9	$3,186,375	$2,326,992	$859,384

Source: Research Triangle Institute.

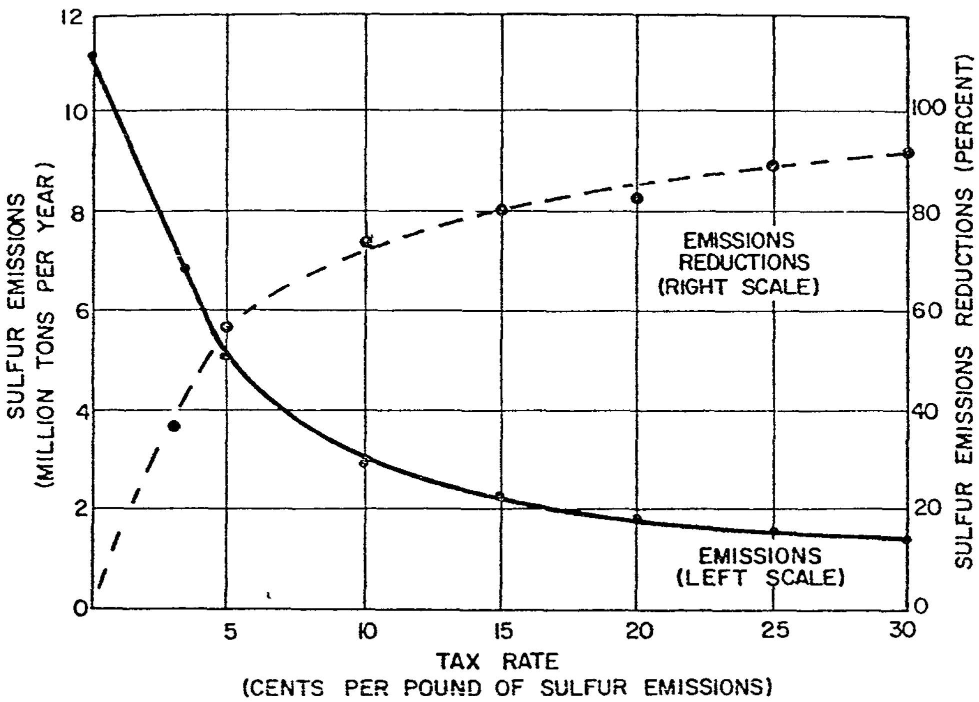

Figure 11. Effectiveness of a tax on sulfur emissions: steam-electric power plants--1978 (Source: Research Triangle Institute).

Table 9 shows the projected percentage distribution of power producing unit's fuel and flue gas cleaning hardware choices in response to increments in the sulfur emissions tax. As the tax is increased, the percentage of producing units that use coal steadily declines (from more than 40 percent with a 5-cent tax to about 23 percent with a 30-cent tax). Although relatively small increases in control hardware are induced among coal-burning plants, large increments are projected for the dry limestone scrubbing systems among oil-burning plants.

Table 10 provides data for the projected distribution of fuel demands by sulfur contents. The table shows the heating values (trillion Btu's) that are projected to derive from domestic and imported residual oil and from domestically produced coal. Bearing in mind that the simulation model presumed unlimited supplies of foreign residual oils at the prices given in appendix A, the reader will note the substantial shift by power plants away from coal to residual oil in the presence of increasing emissions tax rates. For example, at a zero tax rate, coal would constitute more than 76 percent of the total coat- and oil-heat input to power plant boilers; at a 15-cent tax rate, about 48 percent; and at a 30-cent tax rate, only

Table 9. Effects of the sulfur emissions tax on the distribution of flue gas desulfurization choices for steam-electric power producing units*

	Tax rate (cents per pound of sulfur emissions)					
	5	10	15	20	25	30
Coal combustion						
No hardware	35.8	28.1	23.3	21.9	19.2	17.2
Dry limestone	0.9	1.9	2.4	1.8	1.6	1.4
Wet limestone	0.1	0.0	0.0	0.0	0.0	0.0
Magnesia base	3.6	3.7	3.7	4.0	4.2	4.3
Total	40.4	33.9	29.4	27.7	25.0	22.9
Oil combustion						
No hardware	53.4	58.9	56.4	52.1	49.7	47.4
Dry limestone	3.1	4.3	11.1	17.1	22.2	26.6
Wet limestone	0.1	0.1	0.1	0.1	0.1	0.0
Magnesia base	3.0	3.0	3.0	3.0	3.0	3.1
Total	59.6	66.3	70.6	72.3	75.0	77.1

*Generally, boiler(s) with a common size, age, and fuel were treated as the producing unit. For small plants, data inadequacies required that the entire plant be treated as the producing unit.

Note: At a zero tax rate, no additional flue gas desulfurization would be induced.

Source: Research Triangle Institute.

Table 10. Distribution of steam-electric utilities demand for coal and residual oil by sulfur content--1978 (trillion Btu)

	Coal										Residual oil						
	Sulfur content (percent)									Totals	Sulfur content (percent)					Totals	Implied† imports
	0.7	0.9	1.3	1.8	2.3	2.8	3.3	3.8	5.0		0.4	0.6	1.2	2.3	3.0		
Projected maximum domestic supply (trillion Btu)	2.4	2.6	1.2	1.8	1.1	1.2	2.6	2.8	1.4	17.1	1.1	0.7	0.3	0.4	0.1	2.6	--
Tax rate*																	
0	0.0	0.6	0.0	0.2	0.7	1.4	2.6	2.9	1.4	9.8	0.0	0.1	0.1	1.2	1.6	3.0	0.4
5	0.6	1.1	1.0	0.1	2.0	0.8	0.1	0.9	1.4	8.0	0.1	1.1	2.2	0.7	0.7	4.8	2.2
10	1.6	0.9	1.6	0.1	0.4	0.1	0.1	0.9	1.4	7.1	0.4	3.5	1.0	0.3	0.6	5.8	3.2
15	1.7	1.0	1.0	0.1	0.0	0.1	0.1	2.1	0.1	6.2	0.9	4.8	0.0	0.4	0.5	6.6	4.0
20	1.8	0.6	0.4	0.0	0.1	0.2	0.2	2.1	0.1	5.5	1.3	5.0	0.0	0.4	0.5	7.2	4.6
25	1.6	0.2	0.0	0.0	0.1	0.3	0.3	2.1	0.0	4.6	3.1	4.1	0.0	0.4	0.5	8.1	5.5
30	0.9	0.2	0.0	0.0	0.3	0.8	0.8	1.2	0.0	4.2	3.9	3.9	0.0	0.4	0.5	8.7	6.1

*Cents per pound of sulfur emissions.

†These are minimum amounts since they do not include the projected residual oil consumption by area sources.

Source: Research Triangle Institute.

33 percent. The demand for imported residual oil is projected in the far right-hand column of table 10. At intermediate tax rates, these values are comparable to current imports of residual oil, for all uses, which are currently on the order of 3.5 trillion Btu's; this implies about a 60-percent increase in residual oil imports by 1978 if all such imports are diverted for use in power generation. In section 4.2.5 the assumption of fixed oil prices is relaxed. The sensitivity analysis performed there indicates the extreme importance of those prices in determining the distribution of demand.

4.2.4 Costs

The total outlays of the steam-electric utilities were shown in table 8 for selected tax rates. Figure 12 displays the allocation of the costs between emissions tax payments and control costs. The latter include both flue gas desulfurization costs and fuel switching premiums. In absolute terms, total tax payments rise from about $515 million at a 5-cent tax rate to about $860 million at a 30-cent tax rate. However, as a percentage of total emission-control-related costs, the share accounted

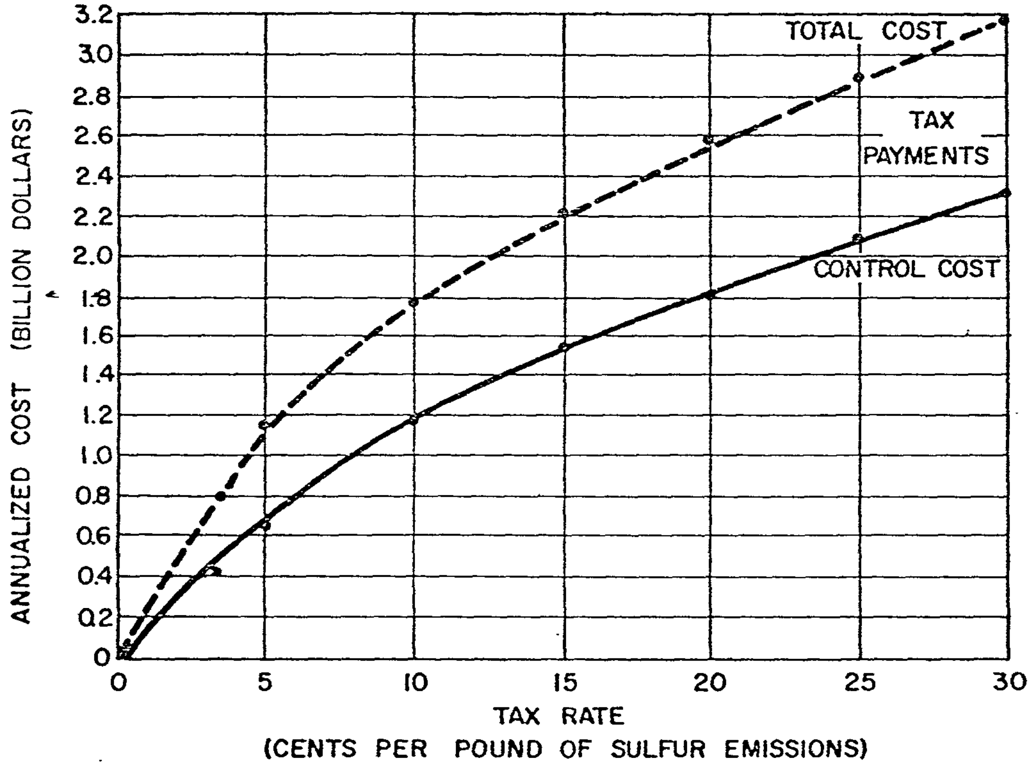

Figure 12. Total costs induced by a tax on sulfur emissions: steam-electric power plants--1978 (Source: Research Triangle Institute).

for by taxes falls from about 44 percent to about 27 percent at tax rates of 5 and 30 cents per pound, respectively. Considering that a 30-cent tax is projected to induce about a 90-percent reduction in emissions (fig. 11) from power plants, this result implies that a policy goal of sulfur emissions reductions of that magnitude can be achieved at only a 27-percent penalty above minimum control costs to the average firm. To society as a whole, there would be no penalty at all since the taxes are merely transfers. Consequently, to the extent that regulation would achieve 90-percent reductions less efficiently than a tax (it cannot be more efficient), all of the additional costs (of achieving that goal) above an estimated $2.3 billion can be considered deadweight losses.

Table 11 gives the distribution of control costs between those for stack gas cleaning and those for fuel switching as the tax rate varies. For a zero tax rate, no additional control is induced, of course. At low tax rates, the distribution is fairly equal; at high tax rates the costs of flue gas cleaning become the larger share since many more utilities are induced to use dry limestone and magnesia base scrubbing systems. Fuel switching costs include net changes not only in the f.o.b. cost of low sulfur fuels but also in transportation expenses. At positive tax rates, the transportation costs are actually projected to be somewhat lower than those with a zero tax since oil (to which utilities are induced to shift,

Table 11. Percentage distribution of control costs

Tax rate*	Flue gas desulfurization	Fuel switching†	Total
5	50.7	49.3	100.0
10	47.4	52.6	100.0
15	51.3	48.7	100.0
20	57.8	42.2	100.0
25	58.9	41.1	100.0
30	62.0	38.0	100.0

*Cents per pound of sulfur emissions.

†These costs are delivered fuel costs at the utility.

Source: Research Triangle Institute.

with the tax and oil prices used) has lower transportation costs per Btu than coal, for most utilities. It is likely, however, that the fuel switching costs are underestimated at high tax rates, for if the supply of imported oil is not assumed to be perfectly elastic, competitive bidding for limited supplies will increase the price of oil. This possibility is analyzed further in section 4.2.5 below.

Figure 13 gives the average cost increases per kilowatthour, as the tax rate is increased. As a percentage of current average electricity costs (1.6 cents/kWh), a 5-cent tax would induce a 4.3-percent increase in average costs; a 15-cent tax, an 8.7-percent increase; and a 30-cent tax, about a 12-percent increase, These values are based on the assumption that the demand for electricity is perfectly inelastic and do not include the effects of the corporate income tax.

4.2.5 Sensitivity Analysis

The projected effectiveness and costs of a tax on the sulfur emissions of steam-electric utilities are expected to be strongly influenced by fuel availabilities and prices. As discussed above, using projections of the fuel prices without a tax, and then applying a tax, many utilities are

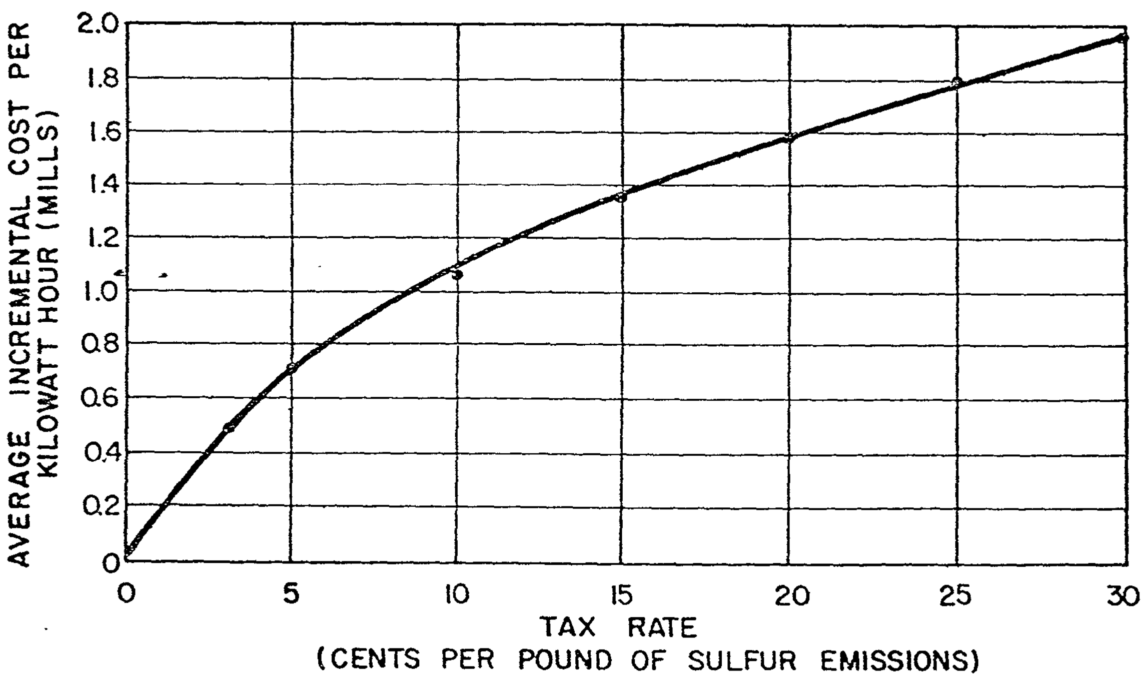

Figure 13. Average total (control cost plus tax payments) incremental costs per kilowatthour induced by a tax on sulfur emissions: steam-electric power plants--1978 (Source: Research Triangle Institute}.

induced to switch from coal to oil to meet their fuel demands at minimum cost, However, such switching will place pressure not only on domestic oil supplies but also on imports. (See appendix A for preliminary estimates of these quantities.) For example, at a tax of only 5 cents, all of the projected supplies of domestic residual oil would be purchased by steam-electric utilities. However, these supplies would provide only two-thirds of demand; the remainder would have to be imported. At higher tax rates, higher imports of oil are required. Furthermore, this assumes that all residual oils are allocated to steam-electric utilities. Industrial and commercial sources are also consumers of residual oil. In 1978, their coal and residual oil requirements are expected to total about 4.1 trillion Btu's. The distribution of their consumption between the two fuels will also depend on relative fuel prices.

All oil prices were increased 20 and then 40 percent to examine the sensitivity of both emissions reductions and total control costs and tax payments to these higher oil prices. The results, shown in table 12, indicate that the oil price increases reduce the projected effectiveness of the tax by the largest percentage increase in emissions at a tax rate of 20 cents; i.e., emissions are about 20 and 29 percent higher when oil prices rise by 20 and 40 percent, respectively. To either side of this rate, the impacts are less (measured as a percentage of emissions) but, nevertheless, still significant. Total emission-control-related costs increase most at low tax rates with the percentage increases tapering off slightly as the tax rate increases.

Besides inducing a general shift toward coal, the increases in oil prices particularly encourage low-sulfur coal consumption. Table 13

Table 12. Sensitivity of effectiveness and total cost of tax on sulfur emissions to residual fuel oil prices: steam-electric power plants--1978

Change in all oil prices (percent)	Change in emissions (percent)						Change in total cost (percent)						Change in annualized control cost (percent)					
	Tax rate (cents per pound of sulfur emissions)						Tax rate (cents per pound of sulfur emissions)						Tax rate cents per pound of sulfur emissions)					
	5	10	15	20	25	30	5	10	15	20	25	30	5	10	15	20	25	30
+20	12.2	15.0	18.5	20.4	16.8	7.9	19.7	18.6	17.8	17.3	17.1	16.6	25.6	20.4	17.4	15.9	17.2	19.8
+40	15.8	20.7	26.5	29.3	20.5	14.4	29.3	26.0	24.7	24.1	23.4	22.8	40.0	28.9	24.0	21.9	24.4	25.9

*Control costs plus tax payments.

Source: Research Triangle Institute.

Table 13. Distribution of steam-electric utilities' demand for coal and residual oil by sulfur content with increased prices for residual oil--1978 (trillion Btu)

	Coal										Residual oil						
	Sulfur content (percent)										Sulfur content (percent)					Totals	Implied† imports
	0.7	0.9	1.3	1.8	2.3	2.8	3.3	3.8	5.0	Totals	0.4	0.6	1.2	2.3	3.0		
Projected maximum domestic supply (trillion Btu)	2.4	2.6	1.2	1.8	1.1	1.2	2.6	2.8	1.4	17.1	1.1	0.7	0.3	0.4	0.1	2.6	--
Tax rate*	Increase in all oil prices of 20 percent																
0	0.0	0.6	0.0	0.2	0.8	1.5	2.2	3.3	2.3	10.9	0.0	0.0	0.0	0.8	1.2	2.0	0.0
5	0.7	1.3	1.1	1.2	2.9	0.8	0.1	0.4	2.2	10.7	0.0	0.7	0.3	0.3	0.8	2.1	0.0
10	2.2	1.5	3.2	0.3	0.4	0.1	0.0	0.5	2.1	10.3	0.2	1.2	0.3	0.4	0.3	2.4	0.0
15	2.3	2.4	1.7	0.1	0.0	0.1	0.0	1.8	0.8	9.2	0.4	2.4	0.1	0.4	0.3	3.6	1.0
20	3.4	1.4	1.2	0.0	0.1	0.3	0.1	2.4	0.1	9.0	0.6	2.5	0.0	0.4	0.3	3.8	1.2
25	3.9	1.2	0.0	0.0	1.6	0.4	0.1	2.5	0.0	9.7	0.6	1.7	0.0	0.5	0.2	3.0	0.4
30	3.6	0.6	0.1	0.0	2.0	0.8	0.4	1.7	0.0	9.2	1.0	1.8	0.0	0.5	0.3	3.6	1.0
	Increase in all oil prices of 40 percent																
0	0.0	0.6	0.0	0.2	0.8	1.5	2.2	3.5	2.3	11.1	0.0	0.0	0.0	0.9	0.7	1.6	0.0
5	0.7	1.3	1.2	1.5	3.0	0.8	0.1	0.4	2.2	11.2	0.0	0.4	0.0	0.5	0.7	1.6	0.0
10	2.5	1.5	3.4	0.6	0.4	0.1	0.0	0.5	2.1	11.1	0.0	0.7	0.1	0.6	0.3	1.7	0.0
15	3.9	2.4	1.9	0.2	0.0	0.1	0.0	1.8	0.8	11.1	0.1	0.7	0.1	0.4	0.2	1.5	0.0
20	5.2	1.4	1.4	0.0	0.1	0.3	0.1	2.5	0.1	11.1	0.2	0.8	0.0	0.5	0.1	1.6	0.0
25	4.9	1.3	0.0	0.0	1.7	0.5	0.1	2.6	0.0	11.1	0.4	0.8	0.0	0.6	0.1	1.8	0.0
30	5.0	0.6	0.1	0.0	2.2	0.8	0.4	1.7	0.0	10.8	0.4	0.9	0.0	0.6	0.1	2.0	0.0

*Cents per pound of sulfur emissions.

†These are minimum amounts since they do not include the projected residual oil consumption by area sources.

Source: Research Triangle Institute.

displays those projected shifts in the presence of 20 and 40 percent oil price increases. Table 14 is analogous to table 9 in that it shows the projected percentage distribution of fuel and flue gas desulfurization choices for power producing units. Compared to the producers' fuel choices under the benchmark prices, the number of coal consuming units is markedly higher, particularly at higher tax rates. Furthermore, the percentages of units using control hardware rise substantially. The most notable increases occur in the addition of dry limestone scrubbers to coal burning boilers.

4.3 Industrial, Commercial, and Residential Space Heating

Projections of the consumption of fossil fuels in industrial, commercial, and residential space heating applications have been made on a State-by-State basis using the emissions and control cost data shown in appendix A. These sources are generally referred to as "area sources" because of the geographically diffused nature of their emissions and because of the difficulty of identifying individual emissions sources. Because of these limited data and of the diversity of size among these industrial, commercial, and residential space heating sources, this analysis provides only a very preliminary examination of the effectiveness and costs of a tax on the sulfur emissions from these area sources. Further, for the same reasons, no sensitivity analysis of the response of the area sources to higher residual oil prices has been included. However, as compared to steam-electric abilities, area sources have fewer control options and, therefore, may reasonably be expected to show larger changes in emissions and total costs than those projected for utilities.

4.3.1 Background

In 1968, industrial, commercial, and residential space heating accounted for 22.8 percent of the estimated nationwide sulfur emissions from all sources.* Because the consumption of residual oil and coal (bearing relatively more sulfur than distillate oil and gas) is concentrated in the industrial and commercial space heating sectors, the predominant share of those emissions can reasonably be attributed to those sources. Table 15 shows the distribution of fuel consumption patterns in 1970, by sources; the reported values confirm the asserted importance of nonresidential sources in the consumption of relatively higher sulfur bearing fuels.

*National Air Pollution Control Administration, Nationwide Inventory of Air Pollutant Emissions--1968, Raleigh, N.C., August 1970.

Table 14. Effects of residual oil price increases on the percentage distributions of flue gas desulfurization choices for steam-electric power producing units*

	Tax rate (cents per pound of sulfur emissions					
	5	10	15	20	25	30
	Increase in all oil prices of 20 percent†					
Coal combustion						
No hardware	46.3	42.3	37.4	35.9	32.6	29.3
Dry limestone	1.1	2.7	4.7	4.7	5.9	6.7
Wet limestone	0.1	0.0	0.0	0.0	0.0	0.0
Magnesia base	4.1	4.2	4.2	4.6	5.1	5.8
Total	51.6	49.2	46.3	45.2	43.6	41.8
Oil combustion						
No hardware	42.5	43.9	43.1	39.7	37.4	35.8
Dry limestone	3.4	4.2	7.9	12.4	16.3	19.8
Wet limestone	0.1	0.1	0.1	0.1	0.1	0.0
Magnesia base	2.5	2.6	2.6	2.6	2.6	2.6
Total	48.5	50.8	53.7	54.8	56.4	58.2
	Increase in all oil prices of 40 percent†					
Coal combustion						
No hardware	48.7	46.9	44.1	43.0	39.8	36.7
Dry limestone	1.2	3.0	5.4	5.8	7.8	9.5
Wet limestone	0.1	0.1	0.1	0.1	0.1	0.1
Magnesia base	4.2	4.2	4.3	4.7	5.4	6.1
Total	54.2	54.2	53.9	53.6	53.1	52.4
Oil combustion						
No hardware	39.7	38.6	36.5	33.0	30.3	28.4
Dry limestone	3.6	4.7	7.1	10.9	14.2	16.7
Wet limestone	0.0	0.0	0.0	0.0	0.0	0.0
Magnesia base	2.5	2.5	2.5	2.5	2.5	2.5
Total	45.8	45.8	46.1	46.4	47.0	47.6

*Generally, boiler(s) with a common size, age, and fuel were treated as the producing unit. For small plants, data inadequacies required that the entire plant be treated as the producing unit.

†Over the values presented in appendix A.

Source: Research Triangle Institute.

Table 15. Area source fuel consumption--1970

Source	Coal (thousand tons)	Residual oil (thousand barrels)	Distillate oil (thousand barrels)	Gas (million cubic feet)
Residential	---	---	447,691	3,206,100
Industrial	210,552	44,190	83,490	2,664,100
Commercial	13,557	73,650	113,812	1,035,900
Total	224,109	117,840	644,993	6,906,100

Source: Research Triangle Institute.

4.3.2 Industry Growth

The growth in the consumption of fossil fuels by these space heating units is expected to follow broad demographic and economic trends. For residential sources, growth was projected to follow the growth in population projected for each State as projected by the Department of Commerce.* For commercial and industrial sources, growth was projected to follow the overall national growth in employment as projected by the Bureau of Labor Statistics.†

4.3.3 Effectiveness

The input demand response of space heating sources to a tax on their sulfur emissions was projected for several tax rates. As discussed in appendix A, the only control alternative permitted is switching to lower sulfur coals or residual oils by the industrial and commercial sources; residential sources are assumed to remain committed to the fuels presently used; viz., distillate oil and natural gas.

It is likely that flue gas cleaning could be employed by some of the larger industrial and commercial sources; however, the lack of data on these sources precluded inclusion of this alternative in this study. If flue gas cleaning is likely, then the effectiveness of the tax would be greater and the total cost less than projected.

Sulfur emissions from area sources, assuming no controls, are projected to be about 5.7 million tons in 1978 (see table 16). The bulk of emissions would come from industrial sources, which would account for 78 percent of

*Survey of Current Business, Volume 52, Number 4, April 1972.

†U. S. Department of Labor, Bureau of Labor Statistics, Patterns of U. S. Economic Growth, BLS Bulletin 1672, Washington, D. C.: U.S. Government Printing Office, 1970.

Table 16. Projected sulfur emissions from area sources--1978*

Source	Annual sulfur emissions (thousand tons of sulfur)
Residential	154
Industrial	4,490
Commercial	1,115
Total	5,759

*Assuming no controls.

Source: Research Triangle Institute.

the total, and commercial sources, projected to generate 20 percent of total emissions.

The projected responses of all area sources to the sulfur tax for selected tax rates are provided in table 17. Reductions in emissions from area sources are projected to increase over the entire range of tax rates considered here. However, the rate of increase falls precipitously above a tax rate of 10 cents per pound of sulfur emissions. For example, a tax rate of 10 cents per pound would induce emissions reductions that are 48 percent greater than those at a 5-cent tax rate. Tripling the tax rate to 30 cents per pound would encourage only an additional 11 percent in emissions reductions compared to those that are projected at a 10-cent tax rate. That sharply exponential response to changes in the tax rate is shown graphically in figure 14.

Table 18 summarizes the demand for coal and residual oil by the fossil fuel combustion sources considered in this report (steam-electric utilities and area sources). The reader is reminded again that these data are of a preliminary nature and based on assumptions as described above and in appendix A. The data in table 18 do show, however, rough magnitudes of the demand responses for several tax rates at the assumed fuel prices. At these prices, higher tax rates (which are inducing substantial emissions reductions) are placing significant pressures on oil supplies, especially imports. If these supplies are not forthcoming at the assumed prices due to an upward sloping supply curve for imported residual oil and/or curtailment of shipments from a major source for political or other purposes, the

Table 17. Projected response of all area sources to a national tax on sulfur emissions--1978

Emissions source	Emissions (thousand tons)	Reductions in emissions from zero tax (thousand tons)	Total annual cost (thousands)	Annualized control cost (thousands)	Annual tax payment (thousands)
	Tax rate:	5 cents per pound of sulfur emissions			
Residential	153.5	0.0	$ 15,350	$ 0	$ 75,350
Industrial	2,203.0	2,206.3	358,925	738,620	220,306
Commercial	498.2	616.5	92,222	42,406	49,876
Total from all sources	2,854.7	2,822.8	$466,497	$787,026	$285,472
	Tax rate:	10 cents per pound of sulfur emissions			
Residential	153.5	0.0	$ 30,701	$ 0	$ 30,701
Industrial	1,063.9	3,345.4	499,202	286,416	212,786
Commercial	276.9	837.8	124,362	68,975	55,387
Total from all sources	1,494.3	4,183.2	$654,265	$355,391	$298,874
	Tax rate:	75 cents per pound of sulfur emissions			
Residential	753.5	0.0	$ 46,057	$ 0	$46,051
Industrial	959.5	3,449.9	598,975	377,142	287,835
Commercial	268.7	846.6	157,621	77,202	80,420
Total from all sources	1,381.1	4,296.5	$796,647	$382,344	$414,306
	Tax rate:	20 cents per pound of sulfur emissions			
Residential	153.5	0.0	$ 61,401	$ 0	$ 61,401
Industrial	956.4	3,452.9	694,752	312,177	382,576
Commercial	267.3	847.4	178,373	77,469	706,904
Total from all sources	1,377.2	4,300.3	$934,526	$383,646	$550,881
	Tax rate:	25 cents per pound of sulfur emissions			
Residential	753.5	0.0	$ 76,751	$ 0	$ 76,751
Industrial	747.8	3,661.5	780,574	406,640	373,934
Commercial	213.9	900.7	202,568	95,574	106,995
Total from all sources	1,115.2	4,562.2	$1,059,893	$502,214	$557,680
	Tax rate:	30 cents per pound of sulfur emissions			
Residential	753.5	0.0	$ 92,107	$ 0	$ 92,701
Industrial	685.7	3,724.2	850,254	439,166	477,088
Commercial	192.3	922.4	222,351	106,987	115,365
Total from all sources	1,030.9	4,646.6	$1,164,706	$546,753	$678,554

Source: Research Triangle Institute.

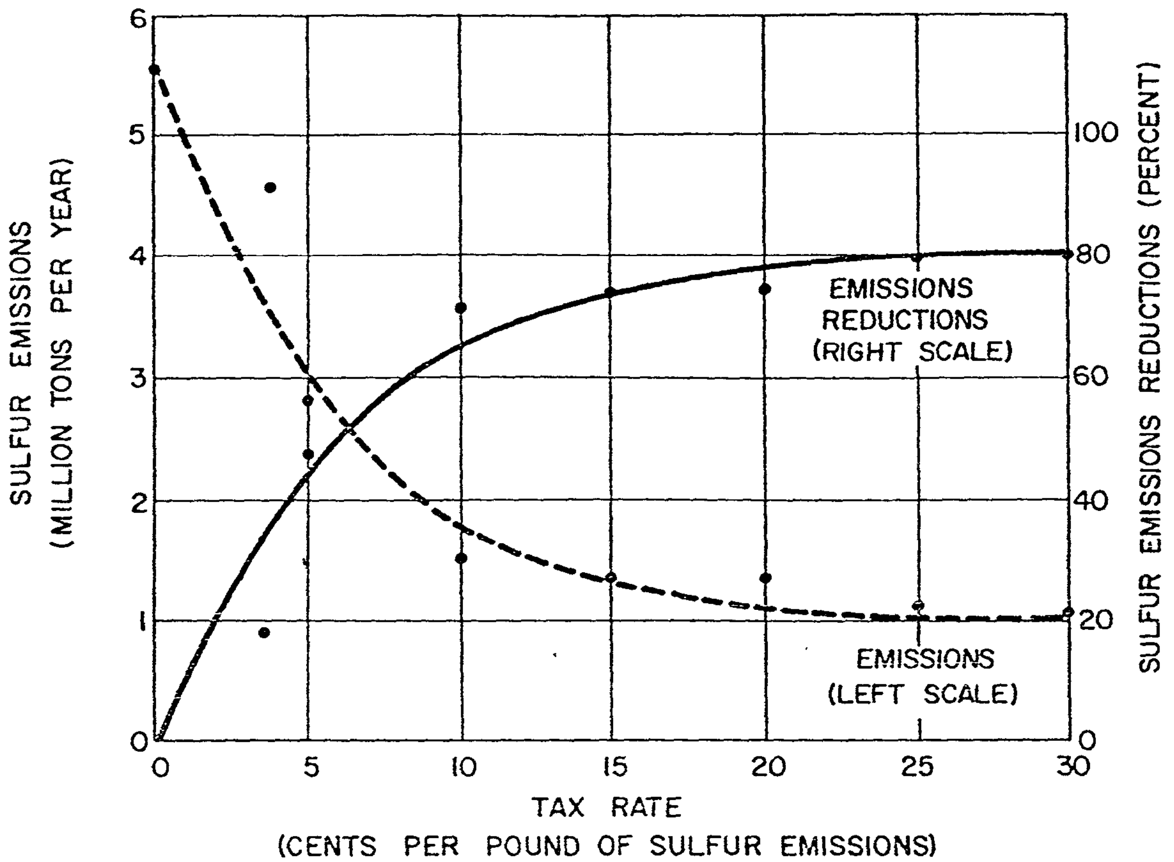

Figure 14. Effectiveness of a tax on sulfur emissions: area sources--l978 (Source: Research Triangle Institute).

Table 18. Distribution of the combined demand of steam-electric utilities and area sources for coal and residual oil--l978

Tax rate	Coal demand (trillion Btu) Utilities	Area sources	Totals	Residual oil demand (trillion Btu) Utilities	Area sources	Totals	Implied imports
0	1.4	9.8	11.2	2.7	3.0	5.7	3.1
5	1.1	8.0	9.1	3.0	4.8	7.8	5.2
10	0.7	7.1	7.8	3.4	5.8	9.2	6.6
15	0.2	6.2	6.8	3.9	6.6	10.5	7.9
20	0.2	5.5	5.7	3.9	7.2	11.1	8.5
25	0.2	4.6	4.8	3.9	8.1	12.0	9.4
30	0.2	4.2	4.4	3.9	8.7	12.6	10.0

Source: Research Triangle Institute.

effectiveness of the tax would be reduced and the cost increased over that projected here. It should be noted, however, that under regulatory approaches to achieving emissions reductions, cost increases would also occur.

4.3.4 Costs

The total cost by the area sources are shown in table 17 and figure 15. The broken curve in figure 15 incorporates both tax payments and fuel switching premiums. The costs for residential sources increase linearly with higher tax rates since no fuel switching or emissions control options for those sources are considered in the simulation model. However, the total cost function for all area sources combined increases at a decreasing rate since emissions control among industrial and commercial sources is induced by the tax.

4.4 Petroleum Refineries

Projections of the response of the nation's petroleum refineries to a tax on sulfur emissions have been made on a plant-by-plant basis, using the emissions and control data shown in appendix B; these projections are summed to obtain industry totals. However, the resulting projections

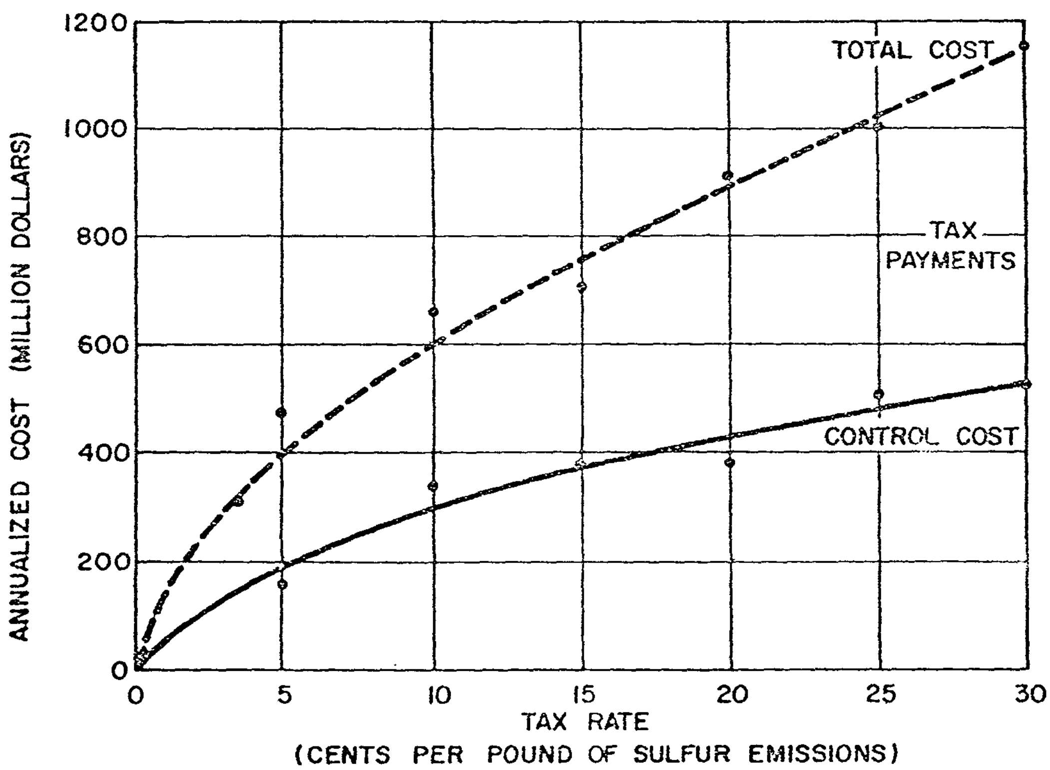

Figure 15. Total cost induced by a tax on sulfur emissions: area sources--1978 (Source: Research Triangle Institute).

are approximations that do not reflect all of the variations in process types and operating procedures among refineries. In addition, emissions may be understated, since the available data do not make it possible to account for the disposition of all of the sulfur contained in the crude oil processed.

4.4.1 Background

In 1968, petroleum refineries accounted for an estimated 6.3 percent of the estimated nationwide sulfur emissions from all sources.* Petroleum products are widely used in other industries, especially as fuel for the generation of electricity, as feedstock for the petrochemical industry, and as the basic material for asphalt roofing and paving. Therefore, their supply and price behavior are important to the economy beyond the influence of their better known, direct uses as vehicle fuels and heating oils.

There were 263 petroleum refineries in the United States in 1970. The bulk of refining capacity is concentrated in 30 to 35 firms. Of these, 16 are fully integrated international corporations making up the so-called large majors of the industry; another 8 firms may be classified as small majors and are also fully integrated. The remainder of the firms in the industry are somewhat smaller; they either are not fully integrated or operate in a limited market. In 1970, petroleum refining capacity was about 12.154 million barrels daily,† and annual production, as measured by actual runs-to-stills, was 3,967.5 million barrels (see fig. 16).

4.4.2 Industry Growth

From 1950 through 1970, petroleum refining (measured by runs-to-stills) increased an average of 3.2 percent annually. However, as shown in figure 16, growth has varied throughout the period. For the period 1970-78, the annual growth rate assumed for petroleum refining is 4 percent.‡ This implies domestic refining of approximately 5,268.8 million barrels in 1978.

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*National Air Pollution Control Administration, Nationwide Inventory of Air Pollutant Emissions--1968, Raleigh, N. C., August 1970.

†Petroleum Refinery Listing, Research Triangle Institute.

‡Research Triangle Institute, Unpublished Data for the Cost of Clean Air, 1973.

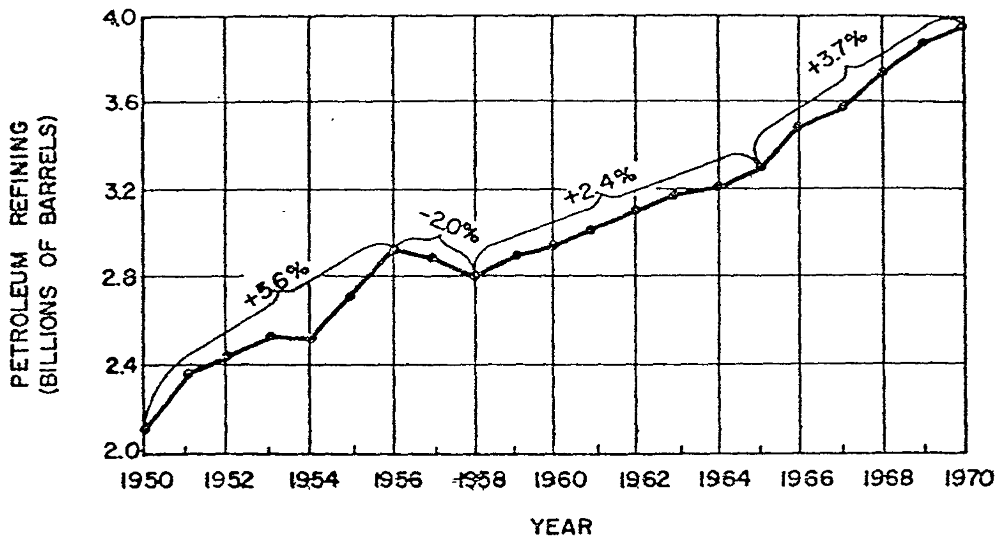

Figure 16. Petroleum refining trends (Source: Research Triangle Institute).

4.4.3 Effectiveness

The response of the nation's petroleum refining industry to a tax on their emissions of sulfur has been projected for several tax rates ranging from 0 to 30 cents per pound of sulfur. Since all of the emissions control alternatives available to refineries and costed for this study result in the recovery of sulfur, it is necessary to credit revenues from its sale. However, because of the uncertainties surrounding the future price of recovered sulfur, the impact of the assumed market price of recovered sulfur on the decisions by refineries to control emissions is analyzed separately in section 4.4.5. In this section, a sulfur price of $10 per ton was used as the most likely 1978 market value for recovered sulfur from petroleum refineries (see appendix E for an extended discussion of this choice).

Sulfur emissions from all petroleum refineries, assuming no additional controls other than those required by New Source Performance Standards (a zero tax), are projected to be about 772,000 tons in 1978 (see table 19). These projected emissions are fairly equally distributed across the three major process sources (Claus plants, catalytic crackers, and fuel oil combustion).

Tabular results of the projected response of all petroleum refineries to the sulfur tax for several tax rates are provided in table 20. This

Table 19. Projected sulfur emissions from petroleum refineries--1978*

Source	Annual sulfur emissions (thousand tons of sulfur)
Claus plants	280
Fluid catalytic crackers	256
Fuel combustion processes	221
Thermofor and Houdriflow catalytic cracker	15
Total	772

*Assuming only controls required by New Source Performance Standards.
Source: Research Triangle Institute.

information, plus the effect of several additional tax rates, is graphically presented in figure 17. Throughout the range of taxes being considered, the only economically feasible control option was the extended treatment of the hydrogen sulfide gas stream via Claus plants or via additions to present Claus plants. No control is induced for emissions from refinery combustion processes or from catalytic crackers because of the high costs of the control alternatives. A large refinery, for example, would find it uneconomical to control emissions from combustion processes until a tax of about 33 cents is introduced. Catalytic cracker emissions would not be controlled until a tax of about $1.60 is introduced. As a result, only 36 percent of the projected emissions would be controlled even with a 30-cent tax. However, the tax payments on emissions from these two sources might encourage the development of other, more cost-effective control techniques than those currently available,

At a tax rate as low as 1 cent, the average large refinery without a Claus plant would find it more economical to install such a plant rather than to pay the maximum amount of tax. At a 2- or 3-cent tax rate, large refineries with two-stage Claus plants are projected to upgrade their plants to four-stage units.

Reductions in emissions are induced by increasing the tax rate to about 20 cents per pound. Tax rates between 20 and 30 cents per pound, however, are projected to induce only small additional reductions in emissions.

Table 20. Projected response of all petroleum refineries to a national tax on sulfur emissions--1978 (recovered sulfur valued at $10 per ton)

Emissions source	Emissions (thousand tons)	Reductions in emissions from zero tax (thousand tons)	Total annual cost (thousands)	Annualized control cost (thousands)	Annual tax payment (thousands)
		Tax rate:	5 cents per pound of sulfur emissions		
Catalyst regenerators	270.6	0.0	$ 27,061	$ 0	$ 27,061
Fluid catalytic crackers	255.5	0.0	25,554	0	25,554
Thermofor and Houdriflow catalytic crackers	15.1	0.0	1,507	0	1,507
Claus plants	116.6	163.7	17,254	5,596	11,659
Fuel combustion	220.9	0.0	22,088	0	22,088
Total from all sources	608.1	163.7	$ 66,403	$5,596	$ 60,808
		Tax rate:	10 cents per pound of sulfur emissions		
Catalyst regenerators	270.5	0.0	$ 54,123	$ 0	$ 54,123
Fluid catalytic crackers	255.5	0.0	51,108	0	51,108
Thermofor and Houdriflow catalytic crackers	15.0	0.0	3,015	0	3,015
Claus plants	46.2	234.0	23,977	14,730	9,247
Fuel combustion	220.8	0.0	44,176	-0	44,176
Total from all sources	537.5	234.0	$122,276	$14,730	$107,546
		Tax rate:	15 cents per pound of sulfur emissions		
Catalyst regenerators	270.5	0.0	$ 81,183	$ 0	$ 81,183
Fluid catalytic crackers	255.5	0.0	76,661	0	76,661
Thermofor and Houdriflow catalytic crackers	15.0	0.0	4,522	0	4,522
Claus plants	18.3	261.9	27,184	21,670	5,514
Fuel combustion	220.8	0.0	66,264	0	66,264
Total from all sources	509.6	261.9	$174,631	$21,670	$152,961
		Tax rate:	20 cents per pound of sulfur emissions		
Catalyst regenerators	270.5	0.0	$108,244	$ 0	$108,244
Fluid catalytic crackers	255.5	0.0	102,214	0	102,214
Thermofor and Houdriflow catalytic crackers	15.0	0.0	6,030	0	6,030
Claus plants	8.3	271.9	28,413	25,056	3,357
Fuel combustion	220.8	0.0	88,351	0	88,351
Total from all sources	499.6	271.9	$225,008	$25,056	$199,952
		Tax rate:	25 cents per pound of sulfur emissions		
Catalyst regenerators	270.5	0.0	$135,304	$ 0	$135,304
Fluid catalytic crackers	255.5	0.0	127,768	0	127,768
Thermofor and Houdriflow catalytic crackers	15.0	0.0	7,536	0	7,536
Claus plants	5.9	274.4	29,114	26,161	2,954
Fuel combustion	220.8	0.0	110,438	0	110,438
Total from all sources	497.2	274.4	$274,856	$26,161	$248,696
		Tax rate:	30 cents per pound of sulfur emissions		
Catalyst regenerators	270.6	0.0	$162,366	0	$162,366
Fluid catalytic crackers	255.5	0.0	153,322	0	153,322
Thermofor and Houdriflow catalytic crackers	15.1	0.0	9,044	$ 0	9,044
Claus plants	4.9	275.3	29,640	26,681	2,959
Fuel combustion	220.9	0.0	132,525	0	132,525
Total from all sources	496.4	275.3	$324,519	$26,681	$297,837

Source: Research Triangle Institute.

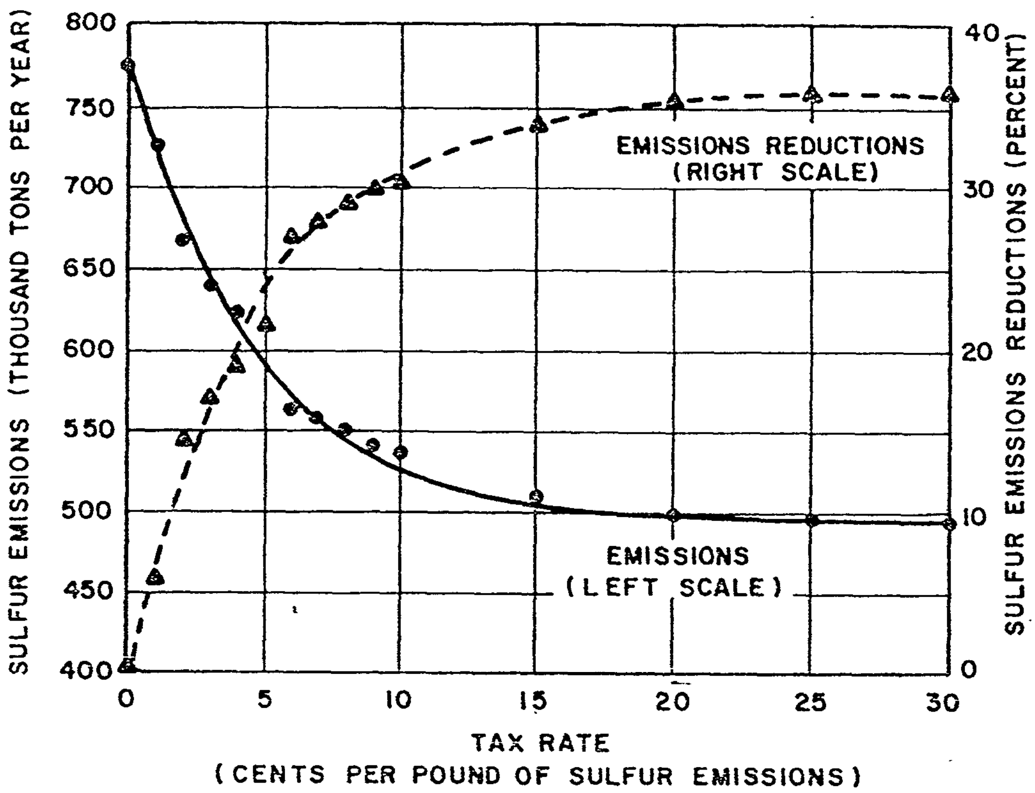

Figure 17. Effectiveness of a tax on sulfur emissions: petroleum refining--1978 (Source: Research Triangle Institute).

4.4.4 Costs

The total cost to the petroleum refining industry is shown in table 20 for selected tax rates. As shown in figure 18, they increase almost linearly for all tax rates between 0 and 30 cents because the majority of the emissions (74 percent) would not be controlled over that range. Since tax rates up to 30 cents are not projected to induce substantial reductions in sulfur emissions, the major cost element over the entire range of taxes would be the tax payments. A remaining defense for the tax, however, is that the continuing tax liability would, very likely, induce the development of more cost-effective alternatives for controlling emissions from catalyst regenerators and fuel combustion than those currently available.

The relative magnitude of these costs on a per-unit-of-product basis assuming a perfectly inelastic demand for petroleum products and not including the effects of the corporate income tax is shown in figure 19. For reference, the 1970 average value at the refinery of all refined petroleum products, exclusive of excise taxes, was about $5.25 per barrel.

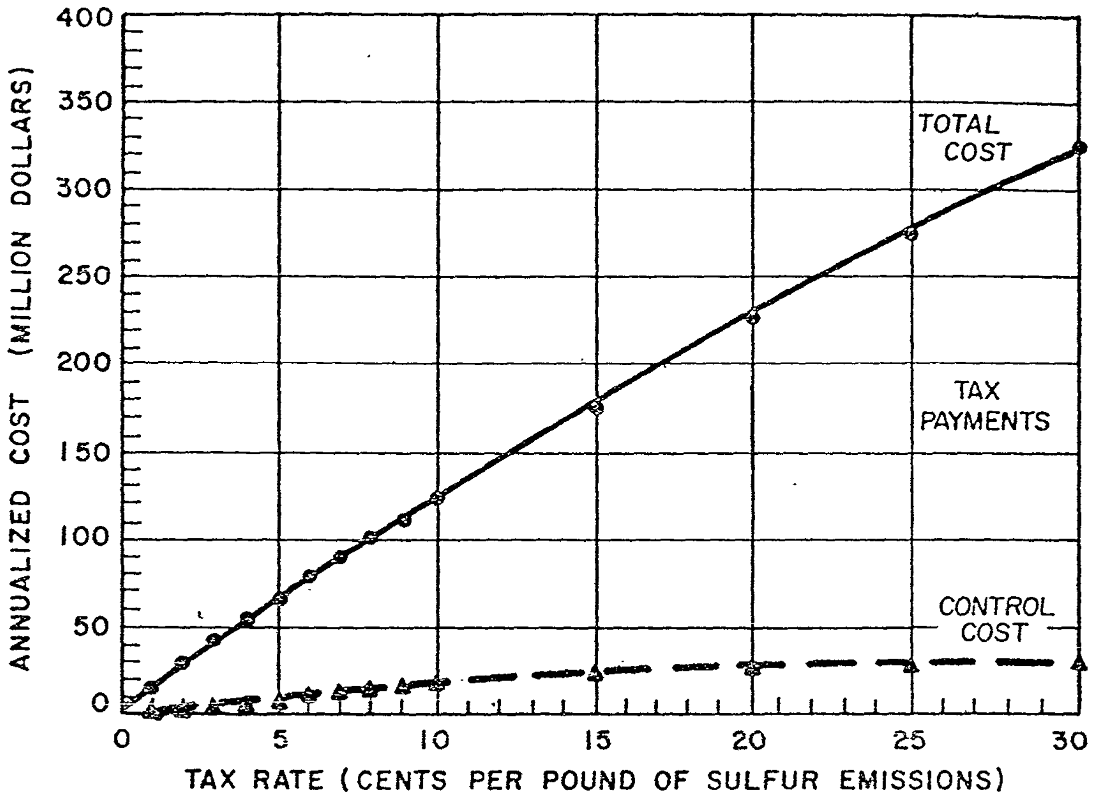

Figure 18. Total costs induced by a tax on sulfur emissions: petroleum refining--1978 (Source: Research Triangle Institute).

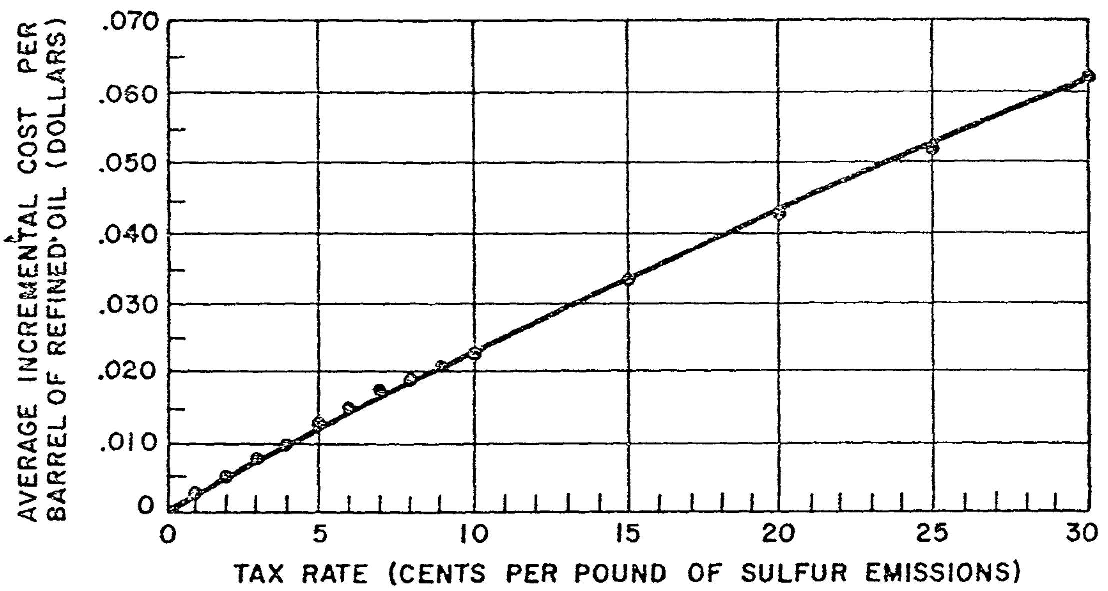

Figure 19. Average total* incremental costs per barrel of refined oil induced by a tax on sulfur emissions: petroleum refining--1978 (*control cost plus tax payments) (Source: Research Triangle Institute).

At a tax rate as high as 30 cents, the sum of control cost and tax payments distributed equally across all refined oil would represent only about one percent of that value.

4.4.5 Sensitivity Analysis

The projected effectiveness and costs of a tax on the sulfur emissions of petroleum refineries is influenced not only by the tax rate, but also by the assumed market value of the recovered sulfur and the estimated control costs of the sulfur emissions control alternatives. To examine the sensitivity of the projected effectiveness and costs of the sulfur tax, a sensitivity analysis was performed. Parametric variations were introduced in the assumed future value for recovered sulfur and in the cost estimates presented in appendix B. The resulting percentage deviations in both emissions and total costs from those which obtain in the presence of the assumed sulfur price of $70 and of control costs as presented in appendix B are given for variations in the price of sulfur in figure 20 and for variations in control costs in table 20. The base values refer to

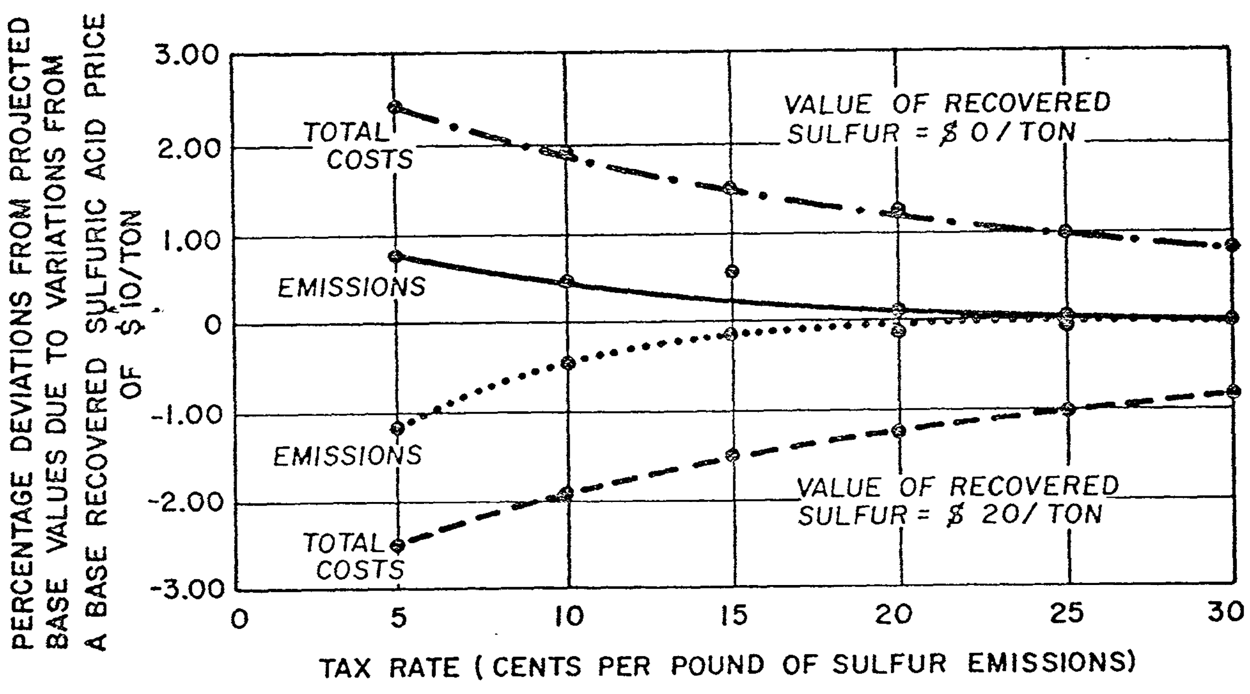

Figure 20. Sensitivity of the effectiveness and total costs of a tax on sulfur emissions to the value of recovered sulfur: petroleum refining--1978 (The base values refer to both the total control costs and the emission levels that obtain when the base sulfur prices is assumed equal to $10 per ton) (Source: Research Triangle Institute).

both the total control costs and the emission levels that obtain when the base sulfur price is assumed equal to $10 per ton.

As is shown in figure 20, reducing or increasing the market value of recovered sulfur by $10 per ton has greater influence at low tax rates. However, the magnitude of those responses is small, never exceeding 2.5 percent. For example, if the value of recovered sulfur were $0 per ton instead of $10 as used in the analysis above, for a tax rate of 10 cents, emissions would be about 0.5 percent and total costs about 2.0 percent higher than projected above. Sulfur emissions and total cost projections under alternative market values of sulfur appear to level off very rapidly as the tax rate is increased, reflecting the decreasing importance of the price of recovered sulfur in influencing the behavior of refineries. The general conclusion of this analysis, then, is that substantial variation in the market price of recovered sulfur is not likely to affect significantly the overall predicted effects of a tax on sulfur emissions from petroleum refineries as discussed in previous sections.

The sensitivity of the emissions and total cost projections to positive and negative percentage deviations in the control cost estimates are presented in table 21. In general, the projected effectiveness and costs are not significantly influenced by these percentage changes in control costs. However, there is a significant exception. Control costs estimates

Table 21. Sensitivity of the effectiveness and total cost of a tax on sulfur emissions to the control cost estimates: petroleum refineries--1978

Change in all control cost estimates (percent)	Change in emissions (percent)						Change in total costs (percent)					
	Tax rate (cents per pound of sulfur emissions)						Tax rate (cents per pound of sulfur emissions)					
	5	10	15	20	25	30	5	10	15	20	25	30
+20	2.5	1.8	2.5	1.1	0.4	0.2	2.0	2.6	2.5	2.4	2.1	1.8
+10	0.8	0.9	1.7	0.4	0.2	0.0	1.1	1.4	1.3	1.2	1.0	0.9
+5	0.2	0.5	0.9	0.1	0.1	0.0	0.5	0.7	0.7	0.6	0.5	0.5
-5	-0.3	-0.5	-0.4	-0.2	-0.1	-0.8	-0.6	-0.7	-0.7	-0.6	-0.5	-0.5
-10	-1.2	-0.9	-0.9	-0.3	-0.2	-18.1	-1.2	-1.4	-1.4	-1.3	-1.1	-1.2
-20	-8.0	-2.9	-1.7	-0.5	-0.3	-27.2	-2.9	-3.1	-3.0	-2.5	-2.1	-4.5

Source: Research Triangle Institute.

that are 20 percent lower than those developed for this study would induce petroleum refineries to reduce substantially the sulfur emissions from fuel combustion. With a tax of 30 cents per pound and control costs for desulfurization that are 20 percent lower than those projected in appendix B, emissions from fuel combustion would be reduced by 61 percent or by 134,000 tons from a currently projected level of 221,000 tons from those sources. Overall, emissions would be 27 percent less than those projected without the application of control policies.

4.5 Sulfuric Acid Producers

Projections of the response of the nation's sulfuric acid producers to a tax on sulfur emissions have been made on a plant-by-plant basis using the emissions and control data shown in appendix C; these projections are summed to obtain industry totals. The resulting cost and emission estimates are approximations in that they do not fully reflect variations in process types and operating procedures among sulfuric acid producers due to the discrete nature of this analysis. However, the results are regarded as very reasonable first order estimates.

4.5.1 Background

In 1968, sulfuric acid production accounted for an estimated 1.8 percent of the estimated nationwide sulfur emissions from all sources.* Sulfuric acid is a strong, low priced, inorganic acid utilized in the production of phosphate fertilizers and other industrial chemicals, in the processing of petroleum, in the production of synthetic fabrics, in the pickling of steel, and in many other metallurgical applications.

Most of the nation's approximately 240 sulfuric acid plants are owned by large, diversified corporations. These plants sometimes sell the acid commercially but, more often, the plants provide one link in a vertically integrated company whose final product requires sulfuric acid as an intermediate input. These companies include sulfur and chemical producers, petroleum refineries, fertilizer plants, and smelters.

Over 97 percent of all sulfuric acid is produced by the contact process.† The remainder is produced by the obsolescent lead chamber

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*National Air Pollution Control Administration, Nationwide Inventory of Air Pollutant Emissions--1968, Raleigh, N. C., August 1970.

†Engineering Analysis of Emissions Control Technology for Sulfuric Acid Manufacturing Process, Final Report, Chemical Construction Corporation, New York, N. Y., For National Air Pollution Control Administration, March 1970.

process, currently being phased out. This analysis is limited to a study of the effects of a tax on sulfur emissions from the 183 plants using the contact process; it does not include sulfuric acid production at primary nonferrous smelters or petroleum refineries. Those sources are treated elsewhere in this study.

In 1970, sulfuric acid capacity was about 94,322 tons daily, and production for the year was 29,525 million tons (see fig. 21).

4.5.2 Industry Growth

From 1950 through 1970, sulfuric acid production increased by an average of 4.2 percent annually. However, as shown in figure 27, growth has varied throughout the period.

Expected growth in sulfuric acid capacity allows for two new 1,500-ton-per-day plants each year between 1970 and 1978.* Assuming that the same capacity-to-output relationship exists in 1978 as existed in 1970, 1978 production would be 37.035 million tons. The 1970-78 growth rate, then, is assumed to be 2.9 percent.

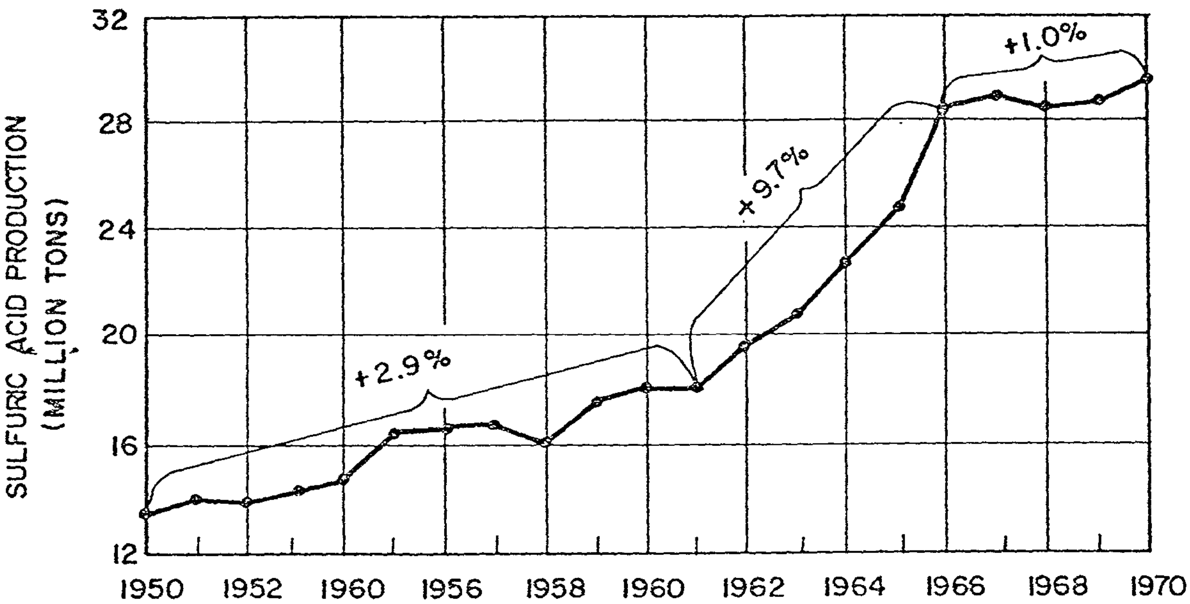

Figure 21. Sulfuric acid production trends (Source: U.S. Department of Commerce).

*Research Triangle Institute, Unpublished Data for the Cost of Clean Air, 1973.

4.5.3 Effectiveness

The reponse of the nation's sulfuric acid industry to a tax on their emissions of sulfur was projected for selected tax rates. Since all of the emissions control alternatives available to this industry and costed for this study result in the recovery or increased production of sulfuric acid, it is reasonable to allow credit for revenues from its sale. Within this section we have used $10 per ton as being the most likely 1978 market value for additional sulfuric acid production from sulfuric acid producers due to the tax. However, because of the uncertainties surrounding the future price of recovered sulfuric acid (see app. E), the impact of the assumed market price of recovered sulfur on the decisions by sulfuric acid producers to control emissions is analyzed separately below (see sec. 4.5.5).

Sulfur emissions from all sulfuric acid producers, assuming no additional control other than those required by New Source Performance Standards (a zero tax), are projected to be about 377,000 tons in 1978 (see table 22).

Tabular results of the projected response of all sulfuric acid producers for several tax rates are provided in table 23. This information is graphically presented in figure 22. Control of sulfur emissions would not be induced below a 5-cent tax rate.

Increasing the tax rate by 10 cents per pound (from 5 to 15 cents) is expected to effect an 84-percent reduction in emissions from the level (385 thousand tons) that would occur at a 5-cent tax rate. Further doubling of the tax rate from 15 to 30 cents per pound of sulfur emitted will yield only a further 22-percent reduction from emissions at the 15-cent tax rate. At a tax rate of 20 cents, 87 percent of potential emissions are expected to be controlled. Beyond that rate, virtually no further reductions are induced.

Table 22. Projected emissions from sulfuric acid production--1978

Source	Annual sulfur emissions (thousand tons of sulfur)
Normal plants, mist	10
Oleum plants, mist	12
All plants, gaseous	354
Total	376

*Assuming only controls required by New Source Performance Standards.

Source: Research Triangle Institute.

Table 23. Projected response of all sulfuric acid plants to a national tax on sulfur emissions--1978 (recovered sulfuric acid valued at $10 per ton)

Emissions source	Emissions (thousand tons)	Reductions in emissions from zero tax (thousand tons)	Total annual cost (thousands)	Annualized control cost (thousands)	Annual tax payment (thousands)
	Tax rate: 5 cents per pound of sulfur emissions				
Gaseous	362.6	0.0	$36,257	$0	$36,257
Mist	22.8	0.0	2,289	0	2,289
Normal	10.7	0.0	1,076	0	1,076
Oleum	12.1	0.0	1,213	0	1,213
Total from all sources	385.4	0.0	$38,546	$0	$38,546
	Tax rate: 10 cents per pound of sulfur emissions				
Gaseous	82.9	279.7	$55,498	$38,927	$16,570
Mist	13.8	9.7	3,912	1,147	2,765
Normal	10.7	0.0	2,152	0	2,152
Oleum	3.1	9.1	1,760	1,147	613
Total from all sources	96.7	288.8	$59,410	$40,074	$19,335
	Tax rate: 15 cents per pound of sulfur emissions				
Gaseous	47.4	315.1	$61,505	$47,269	$74,236
Mist	13.5	9.3	5,292	1,217	4,075
Normal	70.5	0.2	3,228	65	3,163
Oleum	3.0	9.1	2,064	1,152	912
Total from all sources	60.9	324.4	$66,797	$48,486	$18,311
	Tax rate: 20 cents per pound of sulfur emissions				
Gaseous	44.4	318.1	$66,044	$48,270	$17,773
Mist	4.3	13.6	5,974	4,255	1,719
Normal	1.9	8.9	3,613	2,871	742
Oleum	2.4	9.7	2,361	1,384	977
Total from all sources	48.7	336.7	$72,018	$52,525	.$19,492
	Tax rate: 25 cents per pound of sulfur emissions				
Gaseous	44.0	318.5	$70,461	$48,447	$22,014
Mist	3.4	19.4	6,371	4,663	1,708
Normal	1.5	9.2	3,781	3,027	761
Oleum	1.9	10.2	2,589	1,642	947
Total from all sources	47.4	337.9	$76,831	$53,170	$23,722
	Tax rate: 30 cents per pound of sulfur emissions				
Gaseous	43.9	318.6	$74,854	$48,499	$26,356
Mist	3.0	19.9	6,694	4,893	1,801
Normal	1.4	9.3	3,929	3,071	858
Oleum	1.6	10.6	3,929	1,321	949
Total from all sources	46.9	338.5	$81,548	$53,392	$28,158

Source: Research Triangle Institute.

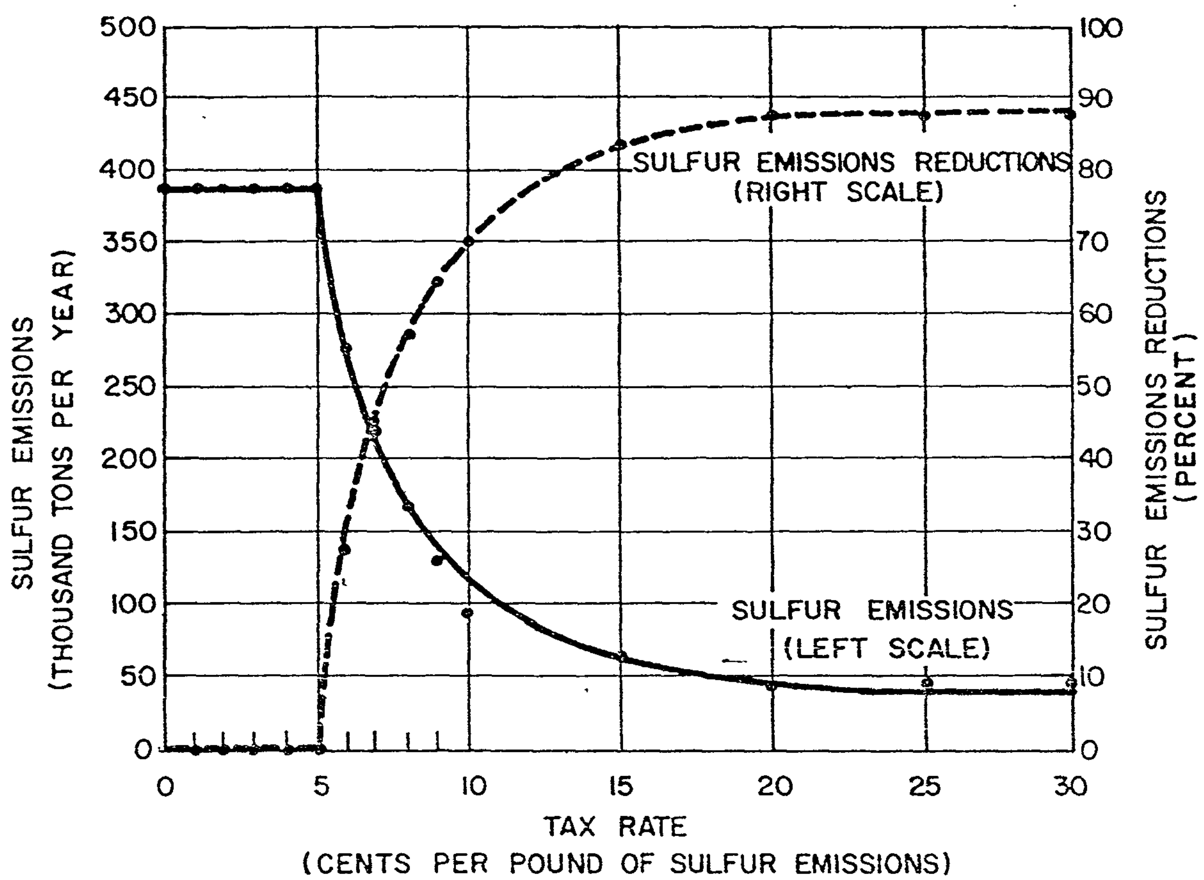

Figure 22. Effectiveness of a tax on sulfur emissions: sulfuric acid producers--1978 (Source: Research Triangle Institute).

4.5.4 Costs

The total annualized cost to the sulfuric acid producers are shown in table 23 for selected tax rates. Those same results are given graphically in figure 23; costs increase at a decreasing rate because relatively small increases in control costs yield significant emission reductions over the 15- to 30-cent tax range. For example, a 10-percent increase in control costs (from $48 to $53 million) causes a 23-percent reduction in emissions.

Some insight of the relative magnitude of these costs (control cost plus tax payments) is shown by allocating them on a per-unit-of-product basis as shown in figure 24. For reference, the 1970 average value of sulfuric acid was about $20 per ton. At a tax rate as high as 30 cents, these costs would represent about 10 percent of that value.

4.5.5 Sensitivity Analysis

The projected effectiveness and costs of a tax on the sulfur emissions of sulfuric acid producers is influenced not only by the tax rate but also

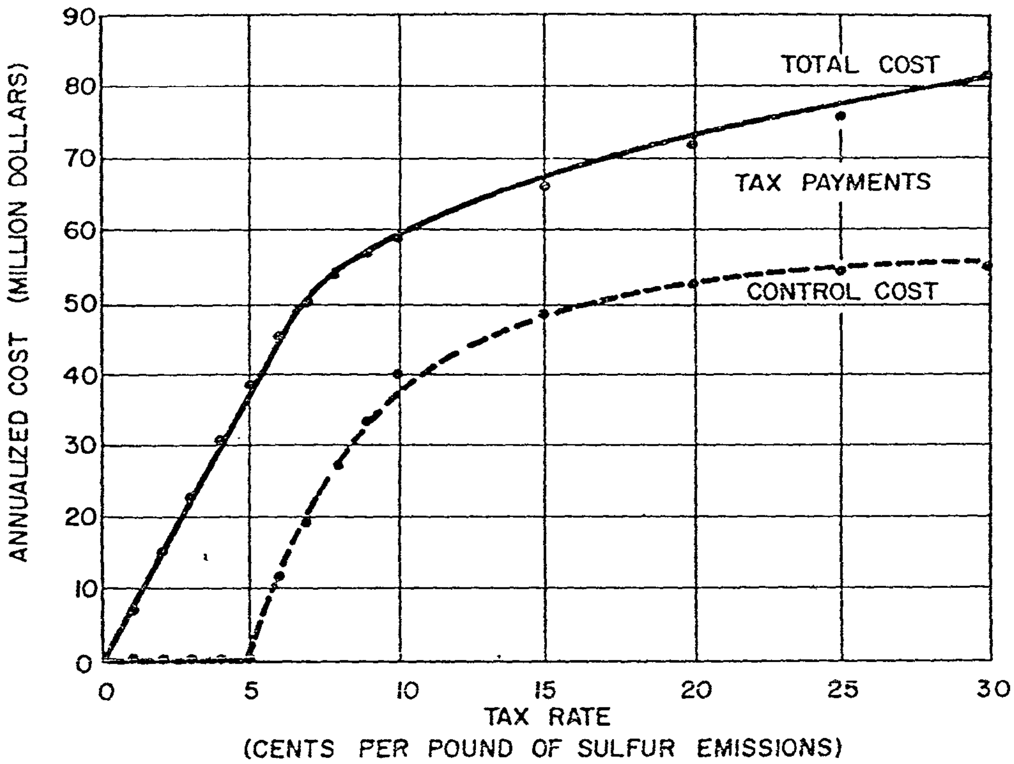

Figure 23. Total costs induced by a tax on sulfur emissions: sulfuric acid producers--1978 (Source: Research Triangle Institute).

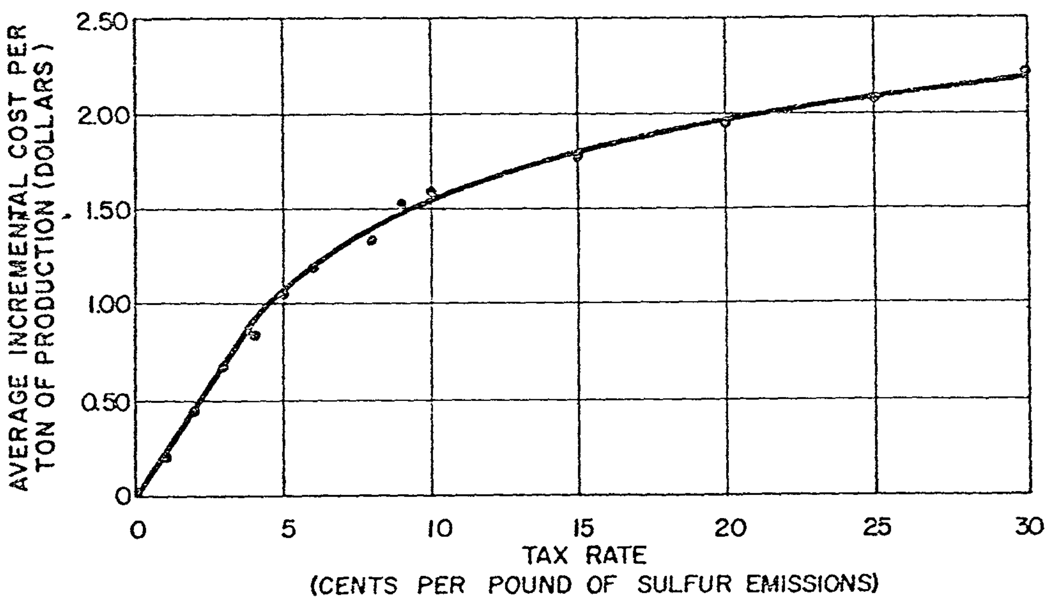

Figure 24. Average total* incremental costs per ton of acid production induced by a tax on sulfur emissions: sulfuric acid producers--1978 (*control cost plus tax payments) (Source: Research Triangle Institute).

by the assumed market value of the recovered sulfuric acid and the estimated control costs of the sulfur emissions control alternatives. To examine the sensitivity of the projected effectiveness and costs of the sulfur tax, a sensitivity analysis was performed. Parametric variations were introduced in the assumed future value for recovered sulfur and in the control cost estimates presented in appendix C. The resulting percentage deviations in emissions and total costs from those which obtain in the presence of the assumed sulfur price of $10 and of control costs as presented in appendix C are given for variations in the price of sulfur in figure 25 and for variations in control costs in table 24.

As shown in figure 25, reducing or increasing the market value of the recovered sulfuric acid by $10 per ton changes projected total costs by about 5 percent in the direction opposite the price change for all tax rates that induce emissions control. For example, if a value of $0 per ton for recovered sulfur is used instead of $10, then for a tax rate of 10 cents,

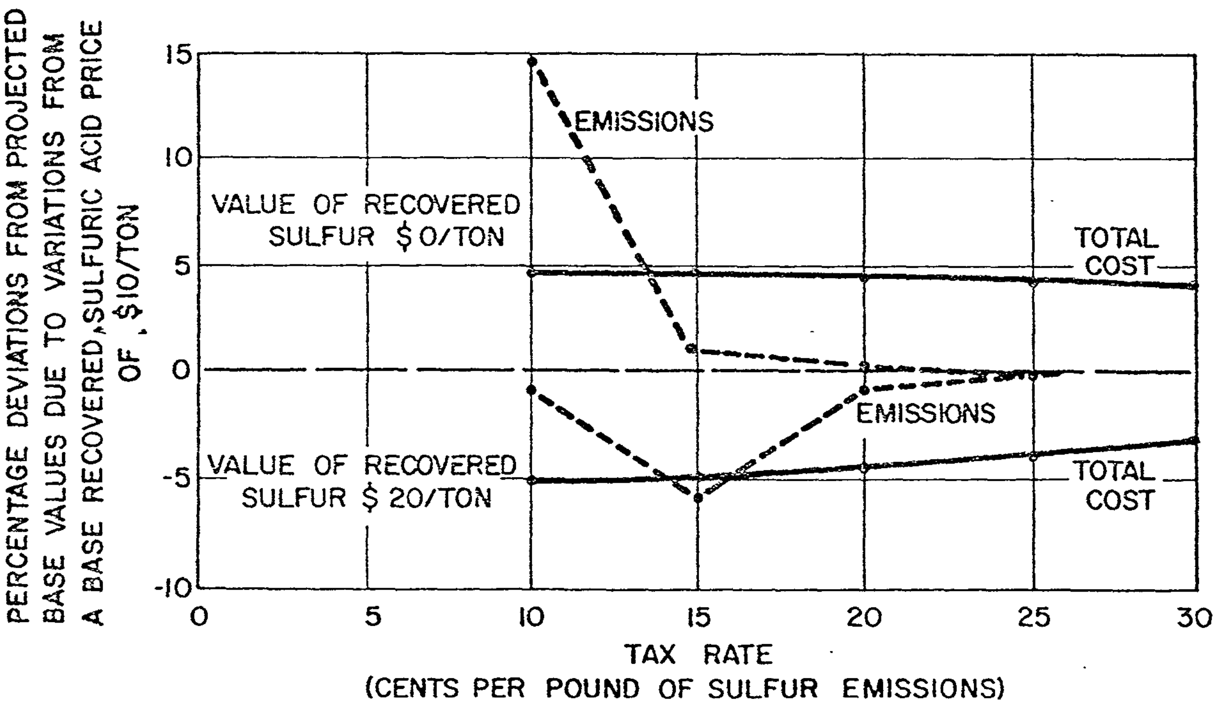

Figure 25. Sensitivity of the effectiveness and total costs of a tax on sulfur emissions to the value of recovered sulfur: sulfuric acid producers--1978 (*The base values refer to both the total control costs and the emission levels that obtain when the base sulfur price is assumed equal to $10 per ton) (Source: Research Triangle Institute).

Table 24. Sensitivity of effectiveness and total costs of tax on sulfur emissions to the control cost estimates: sulfuric acid producers--1978

Change in all control cost estimates (percent)	Change in emissions (percent) Tax rate (cents per pound of sulfur emissions)						Change in total cost (percent) Tax rate (cents per pound of sulfur emissions)					
	5	10	15	20	25	30	5	10	15	20	25	30
+20	0.0	66.1	14.3	6.4	2.3	1.1	0.0	12.5	15.1	15.4	14.6	13.9
+10	0.0	21.2	8.1	2.7	1.3	0.6	0.0	6.7	7.6	7.7	7.3	7.0
+ 5	0.0	14.7	0.4	2.1	0.5	0.4	0.0	3.4	3.9	3.9	3.7	3.5
- 5	0.0	-10.5	- 5.9	-0.4	-0.4	-0.8	0.0	- 3.6	- 3.9	- 3.9	- 3.7	- 3.5
-10	-23.6	-10.6	-15.6	-0.9	-0.6	-1.6	-0.3	- 7.4	- 8.0	- 7.8	- 7.4	-14.0
-20	-31.6	-27.8	-18.0	-2.6	-1.3	-1.0	-3.6	-15.5	-16.2	-15.6	-14.7	- 7.0

Source: Research Triangle Institute.

emissions are 15 percent and total cost 5 percent higher than projected above. These deviations in the price of sulfur would not substantively affect the rate of emissions for any tax rate at or above 20 cents. The largest percentage reduction in emissions, compared to those that occur when the price of sulfur is $10 per ton, occurs at a tax rate of 15 cents when the sulfur price is $20 per ton; that percentage deviation is slightly more than 5 percent. All other such percentage reductions are smaller. On the other hand, when the recovered sulfur is assumed worthless, emissions could increase as much as 15 percent above those levels projected when the value of sulfur is $10 per ton; this most sizable deviation occurs at a tax rate of 10 cents per pound. At tax rates below 10 cents per pound, no emissions reductions are stimulated for any of the chosen variations in sulfur prices.

The sensitivity of the emissions and total cost projections to positive and negative percentage deviations in the control costs estimates are presented in table 24. Reductions in control costs of 10 percent would induce control at 5 cents per pound by some sulfuric acid plants. Emissions are most influenced in the midtax ranges (10 to 15 cents), whereas total costs are most affected by changes of $\pm$ 10 and 20 percent in control costs across all tax rates.

4.6 Primary Nonferrous Smelters

Projections of the response of the nation's primary copper, zinc, and lead smelters to a tax on sulfur emissions have been made on a smelter-by-smelter basis using the emissions and control data shown in appendix D. Individual projections were summed to obtain predictions for the entire industry. The resulting projections, however, are approximations that do not reflect all of the variations in process types and operating procedures among smelters.

4.6.1 Background

Copper, zinc, and lead smelters accounted for an estimated 11.7 percent of the estimated 1968 nationwide sulfur emissions from all sources.* The metals produced from these smelting operations are used in a myriad of applications: for galvanizing, for castings, in electrical equipment and supplies, in brass and bronze products, in storage batteries, and as additives to gasoline. In 1970, primary smelter production capacities in copper (15 plants), zinc (7 plants), and lead (6 plants) were 4,662, 2,236, and 2,114 tons per day, respectively. Actual production figures for 1970, in thousands of tons, were 1,765 (copper), 881 (zinc), and 572 (lead) (see fig. 26).

4.6.2 Industry Growth

From 1950 through 1970, copper production grew fairly steadily (1.8 percent annually) whereas the production growth rates in primary zinc and lead production were both more erratic and lower overall. Copper production is expected to grow 2.2 percent annually reaching 2.101 million tons annually by 1978. Both zinc and lead production were projected to remain at their 1970 levels through 1978, since only negligible growth is anticipated.†

4.6.3 Effectiveness

The response of the nation's primary nonferrous smelters to a tax on their emissions of sulfur were projected for several tax rates between 0 and 30 cents per pound of sulfur. Since the emissions control alternatives costed for primary nonferrous smelters result in the recovery of sulfur, it is necessary to allow credit for revenues from its sale. Within this section we have used $0 per ton as being the most likely 1978 market value for sulfuric acid recovered by nonferrous smelters. This price reflects

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*National Air Pollution Control Administration, Nationwide Inventory of Air Pollutant Emissions--1968, Raleigh, N. C., August 1970.

†Research Triangle Institute, Unpublished Data for the Cost of Clean Air, 1973.

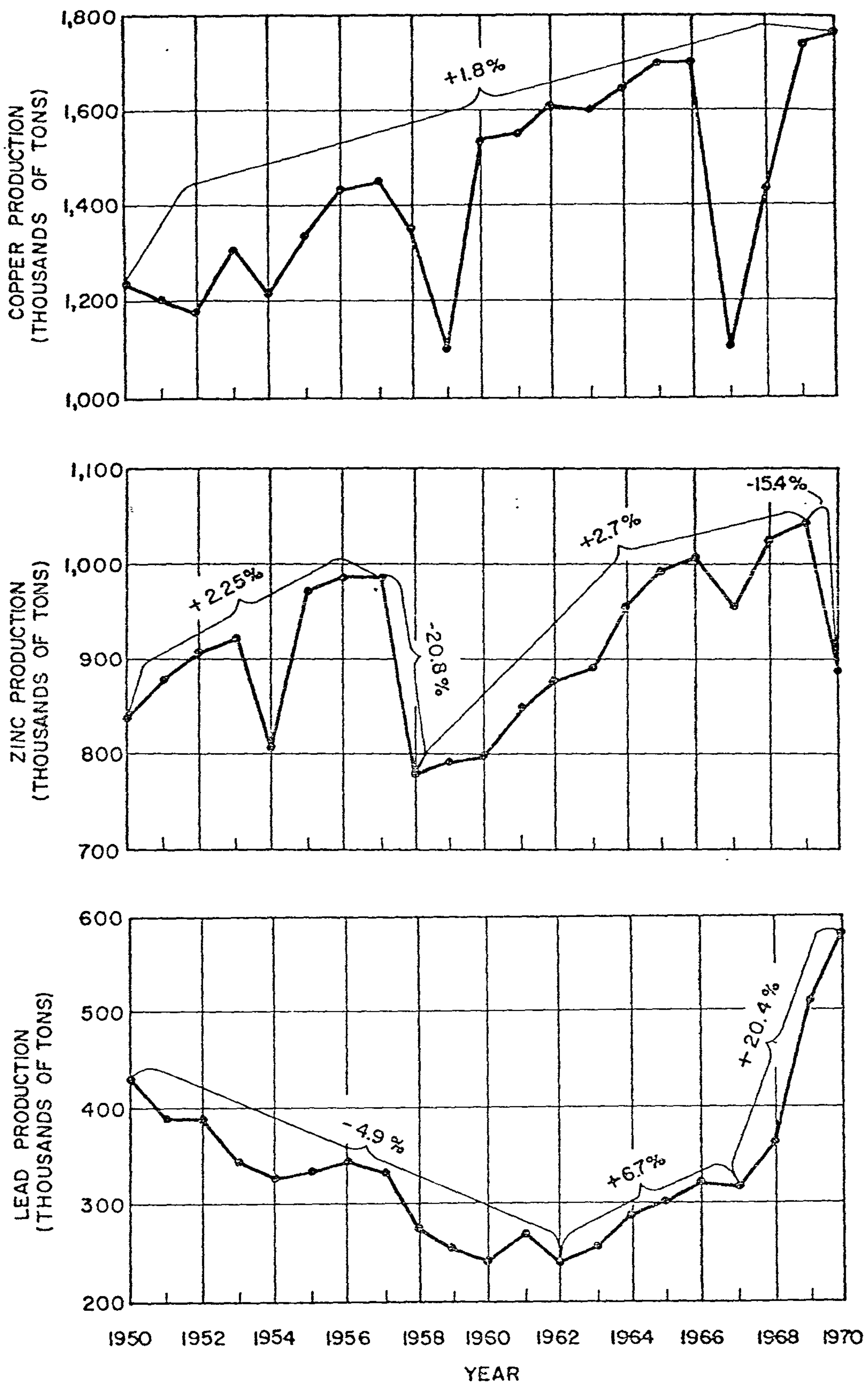

Figure 26. Primary nonferrous smelting trends (*Indicated rates are compounded annual growth rates) (Source: Research Triangle Institute).

the fact that most of the nation's smelters are not located in areas where their recovered acid can be easily sold. However, because of the uncertainties surrounding the future price of recovered sulfuric acid (see app. E), the impact of the assumed market price of recovered sulfuric acid on the decisions by smelters to control emissions is analyzed separately (see sec. 4.6.5).

Sulfur emissions from all nonferrous smelters are projected to be about 1.7 million tons in 1978, assuming a zero tax and no further control inducements (see table 25).

Over 90 percent of all projected sulfur emissions from smelters are from copper smelters, primarily copper smelters without an acid plant. This percentage is greater than copper's share of the total production (measured in tons) of primary nonferrous smelters due to differences in the sulfur content of the three ores and in processing techniques.

Tabular results of the projected response of all primary nonferrous smelters to the sulfur tax for several tax rates are provided in table 26. This information is presented graphically in figure 27.

Tax rates below 5 cents per pound are projected to induce primary nonferrous smelters to reduce substantially their sulfur emissions as compared to those at the zero tax level. For example, the projections indicate that a tax of 2 cents would cause most copper smelters to reduce sulfur emissions to 69 percent of their zero tax level emissions. This would be a reduction of 55 percent in sulfur emissions from all nonferrous smelters taken together. A tax of 3 cents would induce additional control by copper smelters, cause zinc smelters without an acid plant to control,

Table 25. Projected sulfur emissions from primary nonferrous smelters--1978

Source	Annual sulfur emissions (thousand tons of sulfur)
Copper smelters	1,534
Zinc smelters	56
Lead smelters	60
Total	1,650

*Assuming no implementation of emissions standards.

Source: Research Triangle Institute.

Table 26. Projected response of all primary nonferrous smelters to a national tax on sulfur emissions--1978 (recovered sulfur valued at $0 per ton)

Emissions source*	Emissions (thousand tons)	Reductions in emissions from zero tax (thousand tons)	Total annual cost (thousands)	Annualized control cost (thousands)	Annual tax payment (thousands)
	Tax rate: 5 cents per pound of sulfur emissions				
Copper total	248.2	1,286.2	78,070	53,253	24,816
Cu-A	33.5	720.7	32.021	28,674	3,348
Cu-B	30.3	177.3	15,644	12,617	3,027
Cu-C	32.2	118.8	6,372	3,153	3,218
cu-D	152.2	269.4	24,033	8,809	15,224
Zinc total	7.8	47.9	2,563	1,770	793
Zn-A	1.8	43.4	1,550	1,368	182
Zn-B	2.3	4.5	637	402	235
Zn-C	3.7	0.0	376	0	376
Lead total	22.6	37.2	4,465	2,183	2,282
Pb-A	0.6	11.7	947	884	64
Pb-B	1.3	25.5	1,438	1,299	138
Pb-C	20.7	0.0	2,080	0	2,080
Total all sources	278.6	1,371.3	85,098	57,206	27,892
	Tax rate: 10 cents per pound of sulfur emissions				
Copper total	84.2	1,450.5	88,558	71,770	16,789
Cu-A	33.5	720.7	35,369	28,674	6,695
Cu-B	30.5	177.3	18,670	12,617	6,053
Cu-C	2.8	148.2	7.082	6,522	560
Cu-D	17.4	404.3	27,437	23,957	3,481
Zinc total	3.6	52.0	3.040	2.282	758
Zn-A	1.8	43.4	1,732	1,368	364
Zn-B	1.5	5.3	830	511	319
Zn-C	0.3	3.3	478	403	75
Lead total	22.6	37.2	6,746	2,183	4,563
Pb-A	0.6	11.7	1,011	884	128
Pb-B	1.3	25.5	1,576	1,299	276
Pb-C	20.7	0.0	4,159	0	4,159
Total all sources	110.4	1,539.7	98,344	76,235	22,110

See footnotes last page.

Table 26. Projected response of all primary nonferrous smelters to a national tax on sulfur emissions--1978 (recovered sulfur valued at $0 per ton) (con.)

Emissions source*	Emissions (thousand	Reductions in emissions from zero tax (thousand tons)	Total annual cost (thousands)	Annualized control cost (thousands)	Annual tax payment (thousands)
	Tax rate:	15 cents per pound of sulfur emissions			
Copper total	84.0	1,450.4	96,953	71,769	25,184
Cu-A	33.5	720.7	38,717	28,674	10,043
Cu-B	30.3	177.3	21,697	12,6170	9,080
Cu-C	2.8	148.2	7,362	6,522	841
Cu-D	17.4	404.3	29,177	23,957	5,221
Zinc total	3.6	52.0	3,420	2,281	1,138
Zn-A	1.8	43.4	1,915	1,368	546
Zn-B	1.5	5.3	989	511	477
Zn-C	0.3	3.3	516	403	113
Lead total	6.9	52.9	8,464	6,335	2,128
Pb-A	0.6	11.7	1,075	883	191
Pb-B	1.3	25.5	1,714	1,299	415
Pb-C	5.0	15.7	5,675	4,153	1,522
Total all sources	94.8	1,555.6	108,837	80,386	28,451
	Tax rate:	20 cents per pound of sulfur emissions			
Copper total	70.5	1,464.0	104,901	76,707	28,194
Cu-A	20.0	734.2	41,617	33,611	8,006
Cu-B	30.3	177.3	24,724	12,617	12,106
Cu-C	2.8	148.2	7,642	6,522	1,121
Cu-D	17.4	404.3	30,918	23,957	6,961
Zinc total	3.6	52.0	3,798	2,282	1,516
Zn-A	1.8	43.4	2,097	1,368	727
Zn-B	1.5	5.3	1,147	511	638
Zn-C	0.3	3.3	554	403	151
Lead total	6.9	52.9	9,173	6,336	2,838
Pb-A	0.6	11.7	1,139	884	255
Pb-B	1.3	25.5	1,852	1 ,299	553
Pb-C	5.0	15.7	6,182	4,153	2,030
Total all sources	81.0	1,568.9	117,872	85,325	32,548

See footnotes last page.

Table 26. Projected response of all primary nonferrous smelters to a national tax on sulfur emissions--1978 (recovered sulfur valued at $0 per ton) (con.)

Emissions source*	Emissions (thousand tons)	Reductions in emissions from zero tax (thousand tons)	Total annual cost (thousands)	Annualized control cost (thousands)	Annual tax payment (thousands)
	Tax rate:	25 cents per pound of sulfur emissions			
Copper total	68.7	1,465.7	111,832	77,487	34,346
Cu-A	18.2	735.9	43.502	34.391	9,111
Cu-B	30.3	177.3	27,750	12,617	15,133
Cu-C	2.8	148.2	7,922	6,522	1,401
Cu-D	17.4	404.3	32,658	23,957	8,701
Zinc total	3.6	52.0	4.178	2,282	1,897
Zn-A	1.8	43.4	2,279	1,368	911
Zn-B	1.5	5.3	1,308	511	798
Zn-C	0.3	3.3	591	403	188
Lead total	6.9	52.9	9,884	6,335	4,549
Pb-A	0.6	11.7	1,203	883	319
Pb-B	1.3	25.5	1,991	1,299	691
Pb-C	5.0	15.7	6,690	4,153	3,539
Total all sources	79.2	1,570.6	125,894	86,104	40,792
	Tax rate:	30 cents per pound of sulfur emissions			
Copper total	68.7	1,465.7	118,702	77,487	41,216
Cu-A	18.2	735.9	45,324	34,391	10,933
Cu-B	30.3	177.3	30,777	12,617	18,160
Cu-C	2.8	148.2	8,203	6,522	1,681
Cu-D	17.4	404.3	34,398	23,957	10,442
Zinc total	3.3	52.4	4,527	2,466	2,060
Zn-A	1.8	43.4	2,461	1,368	1,093
Zn-B	1.2	5.7	1,437	695	741
Zn-C	0.3	3.3	629	403	226
Lead-total	6.9	52.9	10,592	6,335	4,256
Pb-A	0.6	11.7	1,266	883	383
Pb-B	1.3	25.5	2,129	1,299	829
Pb-C	5.0	15.7	7,197	4,153	3,044
Total all sources	78.9	1,571.0	133,821	86,288	47,532

*Abbreviations:

See Appendix D.

Copper
- Cu-A Green feed--no acid plant
- Cu-B Green feed--with acid plant
- Cu-C Conventional feed-no acid plant
- Cu-D Conventional feed-with acid plant

Lead
- Pb-A Downdraft sintering--no acid plant
- Pb-B Updraft sintering--no acid plant
- Pb-C Updraft sintering--with acid plant

Zinc
- Zn-A Combination roaster--sintering, no acid plant
- Zn-B Roaster with sintering--with acid plant
- Zn-C Roaster with electrolytic purification and acid plant

Source: Research Triange Institute.

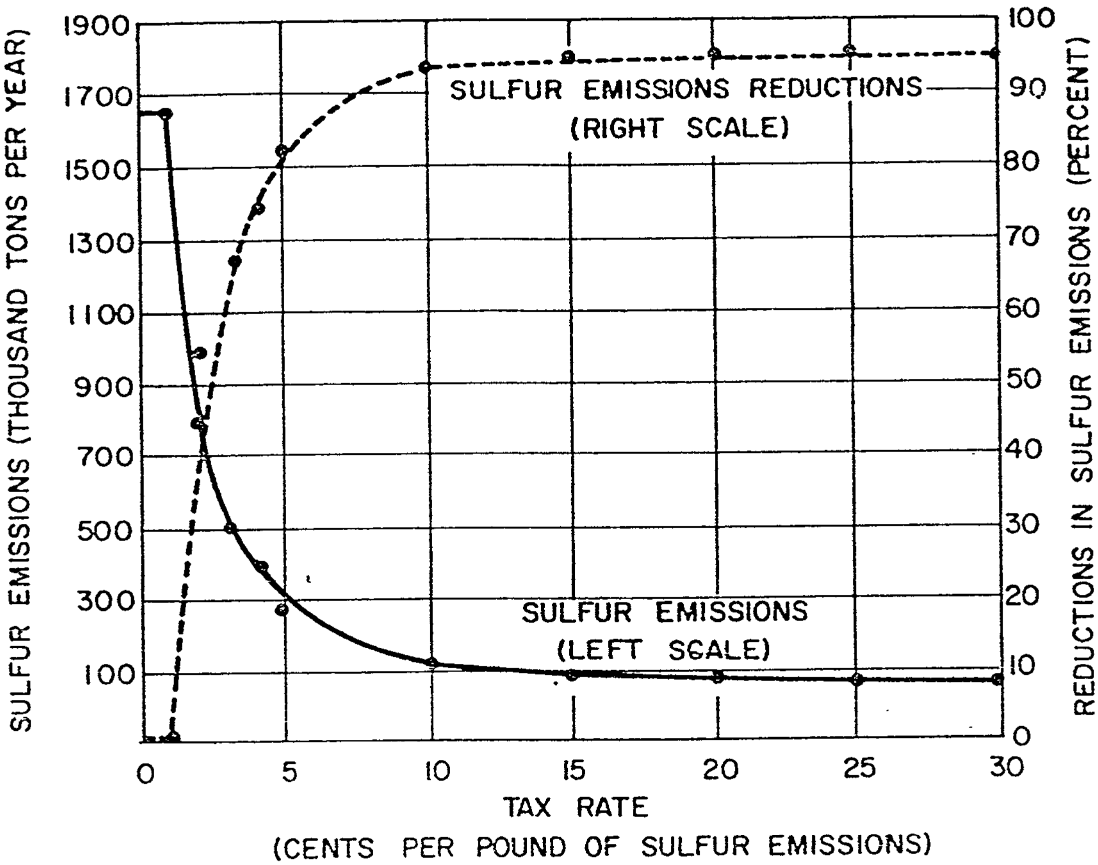

Figure 27. Effectiveness of a tax on sulfur emissions--1978 (Source: Research Triangle Institute).

and some lead smelters would be induced to control. A tax of about 10 cents per pound would cause the last significant reduction in emissions. At this tax, emissions are projected to be only 6 percent of their zero tax level. From 10 to 30 cents per pound, further reductions are projected to be minimal.

4.6.4 Costs

The total cost to the primary nonferrous smelting industry are shown in table 26 for selected tax rates. As graphically shown in figure 28, the total cost to the industry, comprising control costs and tax payments, increase at a generally decreasing rate. This is because of the high levels of emissions control induced by the tax.

These costs are shown on a per-unit-of-product basis in figure 29, assuming a perfectly inelastic demand for the three metals, and exclusive of the impacts the corporate income tax may have on costs. For reference, the 1970 average values of copper, zinc, and lead were $1,259, $306, and

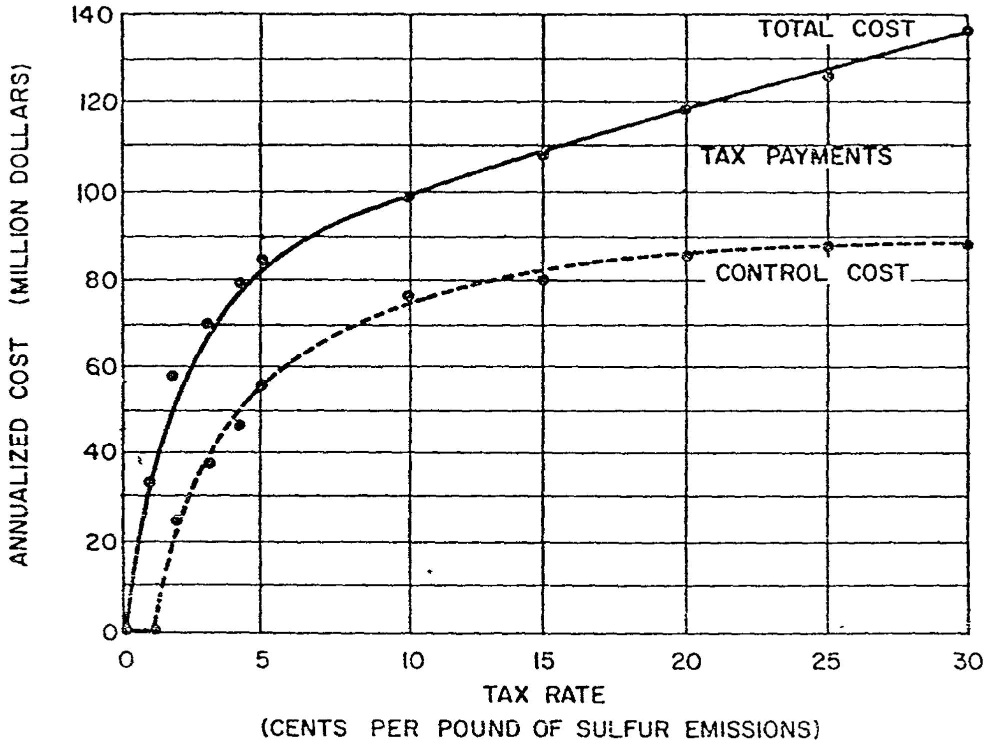

Figure 28. Total costs induced by a tax on sulfur emissions--1978 (Source: Research Triangle Institute).

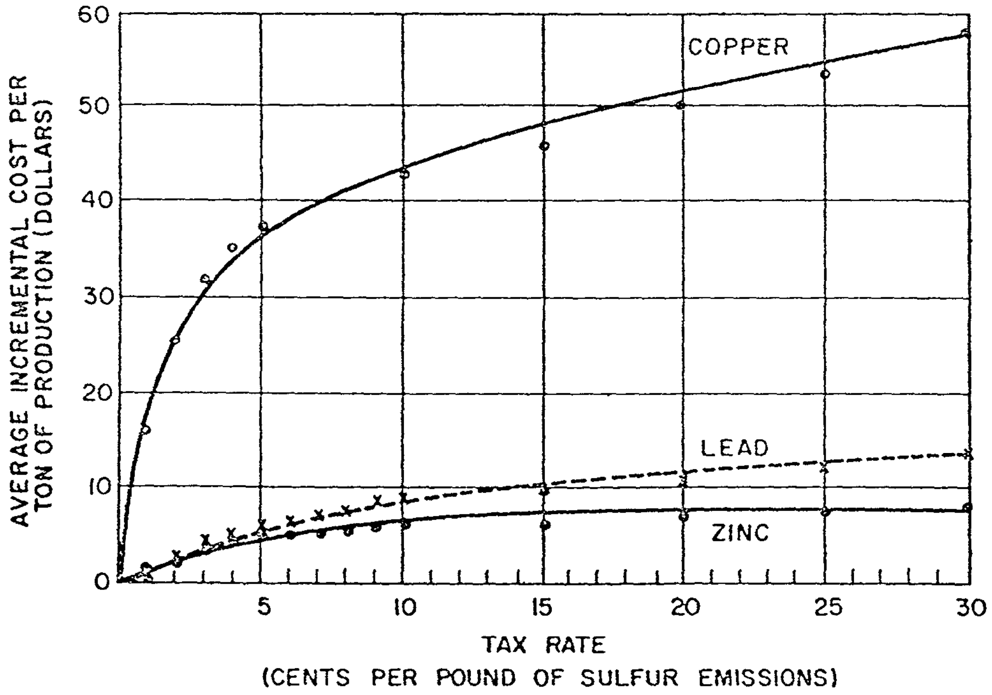

Figure 29. Average total * incremental costs per ton of product induced by a tax on sulfur emissions--1978 (*control cost plus tax payments) (Source: Research Triangle Institute).

$275 per ton, respectively. It appears that at tax rates sufficient to induce control of 94 percent of potential emissions (10 cents), the effect on product prices would be minimal, particularly for lead and zinc.

4.6.5 Sensitivity Analysis

The projected effectiveness and costs of a tax on sulfur emissions of primary nonferrous smelters is influenced not only by the tax rate but also by the assumed market value of the recovered sulfur and the estimated control costs of the sulfur emissions control alternatives. To examine the sensitivity of the projected effectiveness and costs to the assumed future value for recovered sulfur and to the cost estimates presented in appendix D, the percentage deviations in emissions and total costs caused by changes in the value of sulfur and control costs have been examined.

As shown in figure 30, if the sulfuric acid recovered by smelters could be sold at $10 per ton, rather than $0 as used above, the difference in total costs would be fairly significant. Because of the large amounts of sulfur emissions from nonferrous smelters and because of the relatively economical methods for emissions control, sale of the recovered acid at

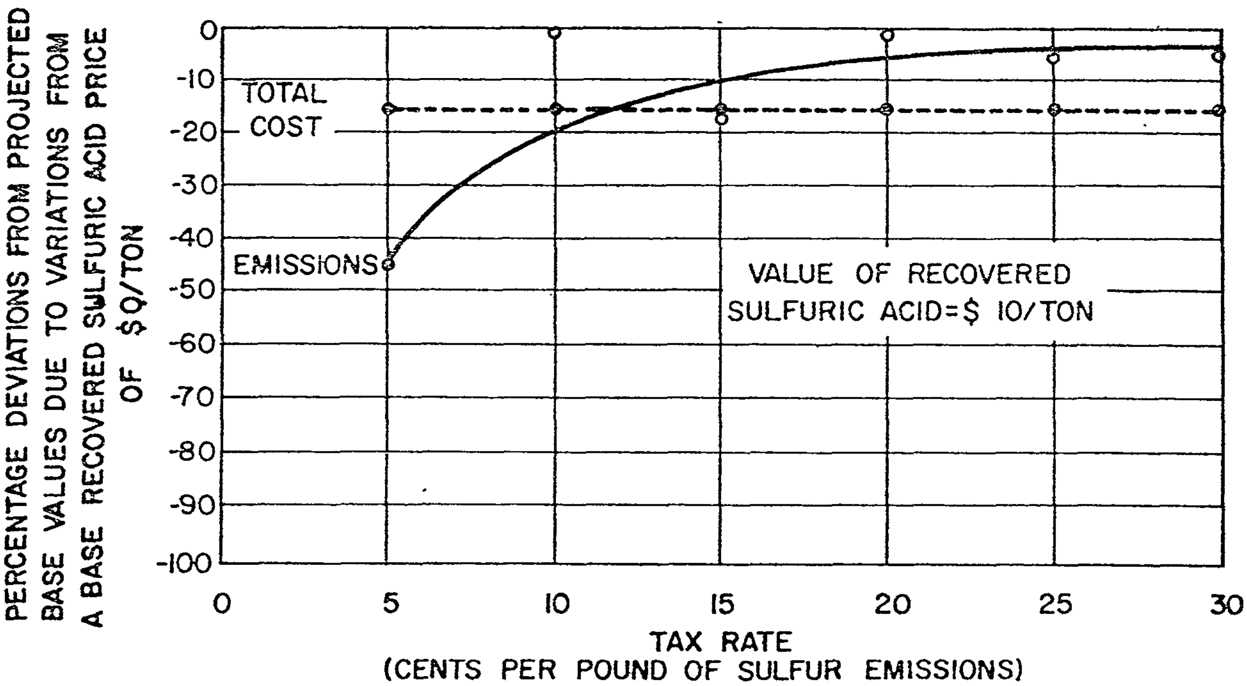

Figure 30. Sensitivity of the effectiveness and total costs of a tax on sulfur emissions to the value of recovered sulfur--1978 (*The base values refer to both the total control costs and the emission levels that obtain when recovered sulfur is worthless) (Source: Research Triangle Institute).

$10 per ton would reduce the costs induced by the tax. Lower costs would also mean lower emissions. For example, at a tax of 5 cents, and a $10 per ton value for recovered sulfur, emissions would be about 45 percent less and total costs 15 percent less than that projected, assuming the recovered sulfur was worthless.

The sensitivity of the emissions and total costs projections to changes in the control costs estimates of ±5, 10, and 20 percent are presented in table 27. Emissions are significantly different from those projected using the cost estimates presented in appendix E for tax rates of only 15 cents and for increases in the control costs of 10 to 20 percent.

Because the schedules of marginal emissions reduction costs, in some cases, are perfectly inelastic over certain ranges of costs, it is possible that what would otherwise appear as unusual predictions would in fact occur. An example of the effect of this inelasticity may be noted in the presence of a 10-percent decrease in control cost estimates (see table 27); a 10- and a 15-cent tax fail to induce additional emissions reductions above those projected (because the marginal cost curve is vertical over that range) but a 20-cent tax stimulates a 2-percent further reduction in emissions (because the marginal cost curve becomes more elastic in that neighborhood of costs). Total control related outlays are never more than 10 percent different from those projected under the assumed regime of control costs unless those costs are raised or lowered 20 percent or more,

Table 27. Sensitivity of effectiveness and total cost of tax on sulfur emissions to control cost estimates: primary nonferrous smelters--1978

Change in all control cost estimates (percent)	Change in emissions (percent)						Change in total cost (percent)					
	Tax rate (cents per pound of sulfur emissions)						Tax rate (cents per pound of sulfur emissions)					
	5	10	15	20	25	30	5	10	15	20	25	30
+20	1.7	0.0	12.2	16.5	2.3	0.5	13.4	15.5	14.5	14.0	13.7	12.9
+10	0.0	0.0	8.2	8.7	0.0	0.0	6.7	7.8	7.4	7.1	6.8	6.5
+ 5	0.0	0.0	0.0	2.7	0.0	0.0	3.4	3.9	3.7	3.6	3.4	3.2
- 5	-16.6	0.0	0.0	0.0	-0.5	0.0	-3.4	-3.9	-14.5	-3.6	-3.4	-3.2
-10	-30.0	0.0	0.0	-2.2	-0.5	-6.1	-7.3	-7.7	-7.4	-7.2	-6.8	-6.5
-20	-50.0	-3.8	-9.4	-2.2	-0.5	-6.1	-15.7	-15.5	-14.9	-14.6	-13.7	-13.2

Source: Research Triangle Institute.